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Special Bridges

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Special Bridges

Topic 12.1 Cable Supported Bridges

12.1.1 Introduction

There are several bridge types which feature special elements and which require special inspection procedures. The most notable special bridge types are:

- Suspension bridges (see Figure 12.1.1)
- Cable-stayed bridges (see Figure 12.1.2)

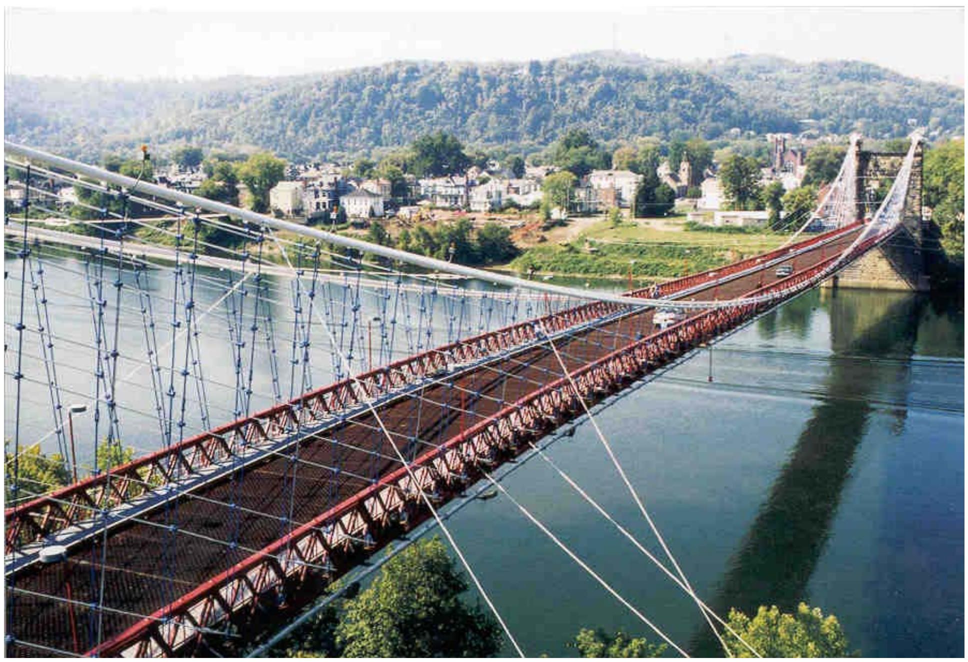


Figure 12.1.1 Wheeling Suspension Bridge – Longest in the World When Completed in 1849 (Photo Courtesy of Geoffrey H. Goldberg, 1999)

Figure 12.1.2 Maysville Cable-Stay Bridge, Built in 2000

This section is limited to the cable and its elements. All other members of a cable-supported bridge have been described in earlier sections and should be referred to for the appropriate information. For each of the above bridge types, this section provides:

- A general description
- Identification of special elements
- An inspection procedure for special elements
- Methods of recordkeeping and documentation

12.1.2 Design Characteristics

A cable-supported bridge is a bridge that is supported by or "suspended from" cables.

Suspension Bridge

A suspension bridge has a deck, which is supported by vertical suspender cables that are in turn supported by main suspension cables. The suspension cables are supported by saddles atop towers and are anchored at their ends. Suspension bridges are normally constructed when intermediate piers are not feasible because of long span requirements. Modern suspension bridge spans are generally longer than 427 m (1400 feet).

Cable-Stayed Bridge

A cable-stayed bridge is another long span cable supported bridge where the superstructure is supported by cables, or stays, passing over or anchored to towers located at the main piers. Cable-stayed bridges are the more modern version of cable-supported brides. Spans generally range from 213 to 427 m (700 to 1400 feet). Evolving for approximately 400 years, the first vehicular cable-stayed bridge in the United States was constructed in Alaska in 1972 (John O'Connell Memorial Bridge at Sitka, Alaska).

Examples

In comparison, cable-stayed bridges are much stiffer than suspension bridges. In cable-stayed bridges, the deck is supported directly from the tower with fairly taut stay cables. In suspension bridges, vertical suspender cables attach the deck to the loosely hung main cables.

- **The Wheeling Suspension Bridge** - also has stay-cables. Suspension bridges normally have an inspection walkway along the main cables. The Wheeling Suspension Bridge in Wheeling, West Virginia was originally built in 1849 (see Figure 12.1.3).

- **Footbridge** - this footbridge shows basic concepts of a suspension bridge, but on a smaller simpler structure (see Figure 12.1.4).

- **Sunshine Skyway Bridge** - multiple towers, concrete superstructure, single cable plane (see Figure 12.1.5)

Figure 12.1.3 Roebling Bridge

Figure 12.1.4 Footbridge Suspension Bridge

Figure 12.1.5 Sunshine Skyway Cable-Stayed Bridge in Tampa Bay, Florida

12.1.3 Suspension Bridges

In this section, only those bridge elements that are unique to suspension bridges are discussed. Refer to the appropriate section for other suspension bridge elements that are common to most bridges.

Main Suspension Cables and Suspender Cables

Main suspension cables are generally supported on saddles at the towers and are anchored at each end. Suspender cables are vertical cables that connect the deck system to the main cables (see Figure 12.1.6). The main cables are commonly composed of a number of parallel wires banded together and wrapped with a soft wire wrapping. Composition of the suspender cables varies.

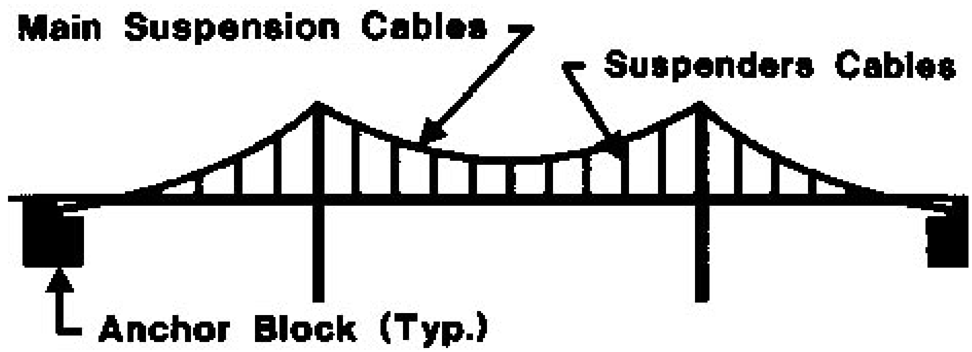


Figure 12.1.6 Three-Span Suspension Bridge Schematic

If a suspension bridge has only two main suspension cables, the cables are considered as fracture critical members. This is due to the non-redundancy (only two load paths) of the main suspension cables. Refer to Section 8.1 for a more detailed description of fracture criticality and redundancy.

Types of Cables

A cable may be composed of one or more structural wire ropes, structural wire strands, locked coil strands, parallel wire strands, or parallel wires.

- **Parallel Wire** - Parallel wire cable consists of a number of parallel wires. Size varies (see Figure 12.1.7)

- **Structural Wire Strand -** Structural wire strand is an assembly of wires formed helically around a center wire in one or more symmetrical layers. Sizes normally range from 50 to 100 mm (2 to 4 inches) (see Figure 12.1.8).

- **Structural Wire Rope -** Structural wire rope is an assembly of strands formed helically around a center strand (see Figure 12.1.9).

- **Parallel Strand Cable -** Parallel strand cable is a parallel group of strands (see Figure 12.1.10).

- **Locked Coil Strand -** Locked coil strand is a helical type strand composed of a number of round wires, then several layers of wedge or keystone shaped wires and finally several layers of Z- or S-shaped wires (see Figure 12.1.11).

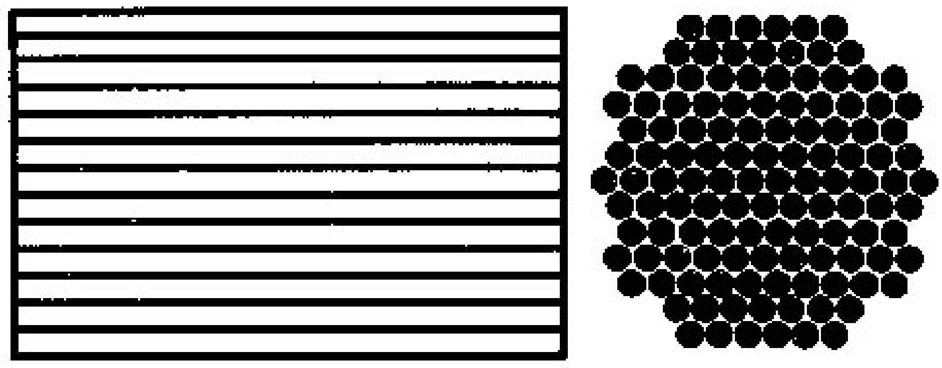


Figure 12.1.7 Parallel Wire Schematic

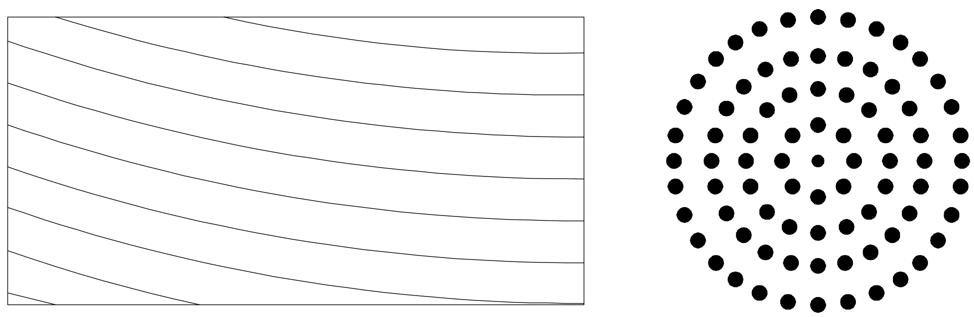


Figure 12.1.8 Structural Wire Strand Schematic

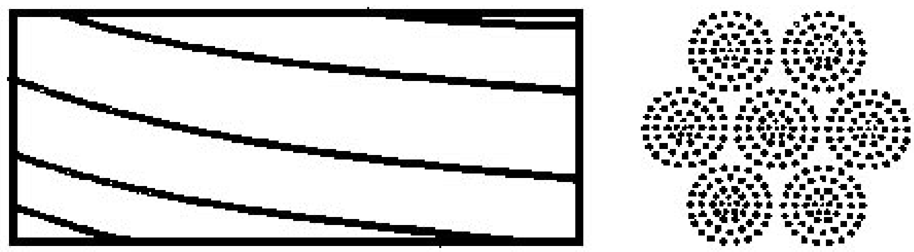


Figure 12.1.9 Structural Wire Rope Schematic

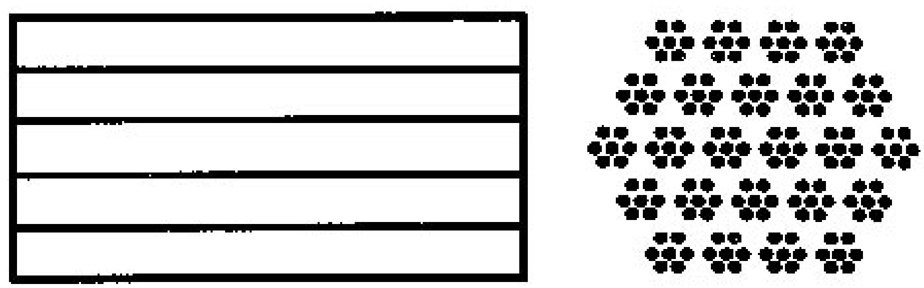


Figure 12.1.10 Parallel Strand Cable Schematic

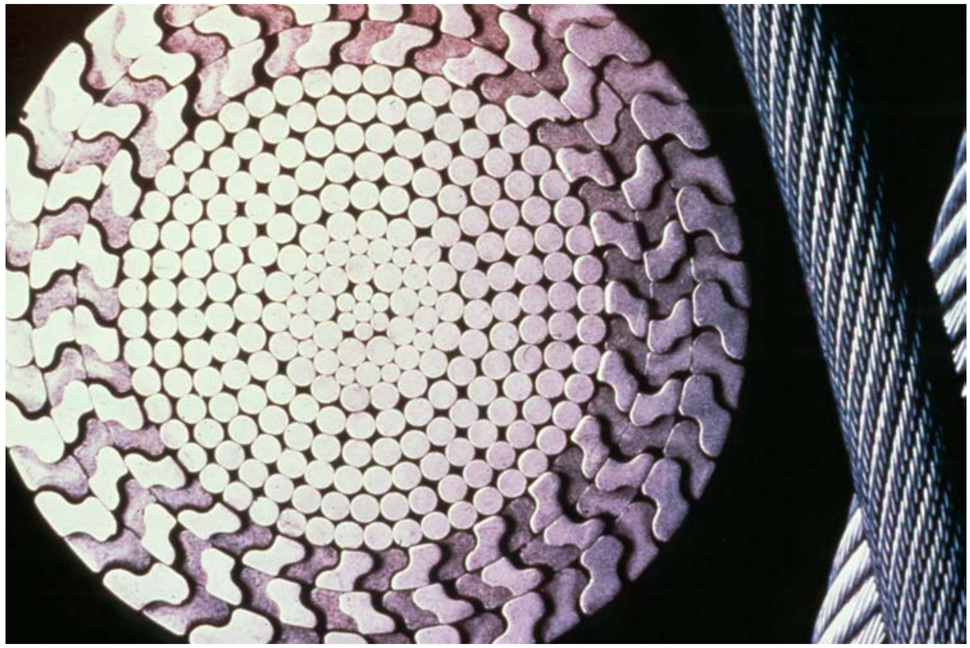


Figure 12.1.11 Locked Coil Strand Cross-Section

Corrosion Protection of Cables

Methods used for corrosion protection include:

- galvanizing the individual wires
- painting the finished cable
- wrapping the finished cable with spirally wound soft galvanized wire, neoprene, or plastic wrap type tape
- any combination of the above systems (see Figure 12.1.12).

Figure 12.1.12 Cable Wrapping on the Wheeling Suspension Bridge

Cable Anchorages

In bridges with common earth anchored cable systems, either above or below ground, the total force of the main cable has to be transferred into the anchor block (see Figure 12.1.13). Force transmission from cable to anchor block is established by anchoring the individual strands to the concrete of the block. Flaring of the strands takes place in the splay chamber. From the strand shoes or sockets the strand forces are transferred to the anchor block by steel bars, rods, pipes, or prestressed bars embedded into the concrete.

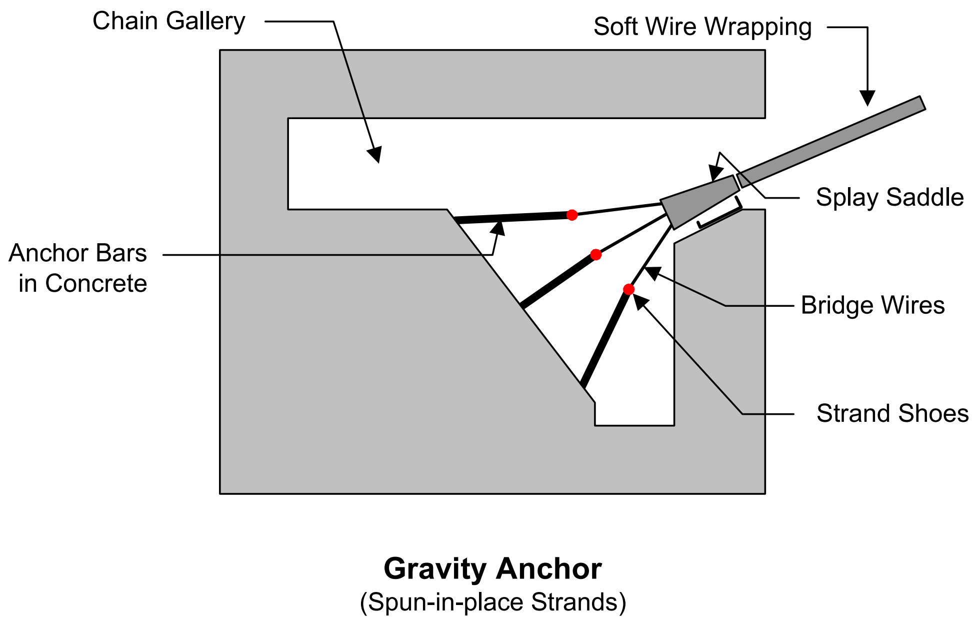


Figure 12.1.13 Gravity Anchor Schematic

Cable Saddles

The connection between cable and tower is usually made through saddles. The saddle supports the cable as it crosses over the tower. Saddles are commonly made from fabricated steel or castings (see Figure 12.1.14).

Figure 12.1.14 Cable Saddles for the Manhattan Bridge, NYC (Main Span 1,480 ft (451.1 m))

Suspender Cable Connections

The connection between the main and suspender cable is made by means of a cable band. The cable band consists of two semi-cylindrical halves connected by high-tensile steel bolts to develop the necessary friction.

- **Groove Cable Bands -** Grooved cable bands have been used in the majority of suspension bridges. The top surfaces of the bands are grooved to receive the suspender cables, which are looped over the band.

- **Open Socket -** Instead of looping the hanger cables around the band, the hanger might also be socketed at the upper end and pin connected to the cable band. This connection is called an open socket (see Figure 12.1.15). Connection to the deck and floor system can also be a similar open socket arrangement or it can be connected directly to a girder - similar to the tied arch bridge.

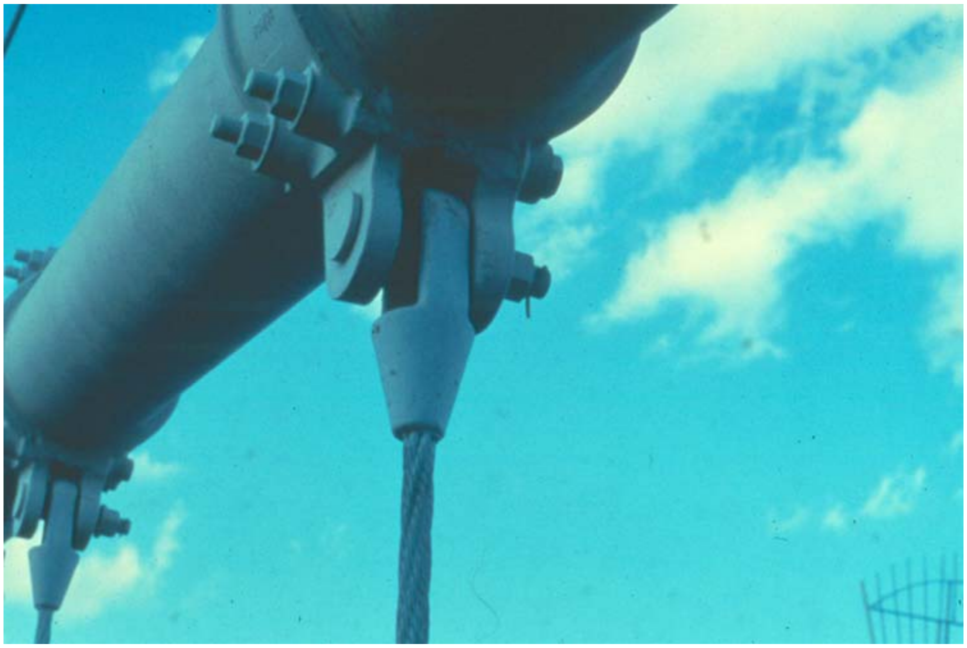


Figure 12.1.15 Open Socket Suspender Cable Connection (Brooklyn Bridge)

Vibrations

The flexibility of cable supported structures, associated with high stress levels in the main load carrying members, makes these structures especially sensitive to dynamic forces caused by earthquake, wind, or vehicular loads. The inspector should always note and describe vibrations whether local or global, while performing inspections of cable-supported structures. The term local vibration is used when dealing with the vibration in an individual member (see Figure 12.1.16). When the vibration of the entire structure as a whole is analyzed, it is known as global vibration (see Figure 12.1.17). Due to the amount of vibration in cable supported structures, it is not uncommon to see various types of damping systems attached to cables. Damping systems may be a tie between two cables, neoprene cushions, shock absorbers mounted directly to the cables, or other systems that act to dampen the cable vibrations.

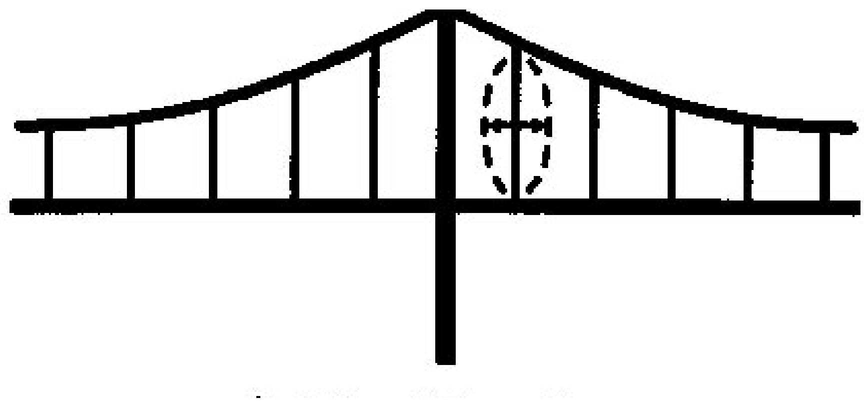


Figure 12.1.16 Cable Vibrations Local System Schematic

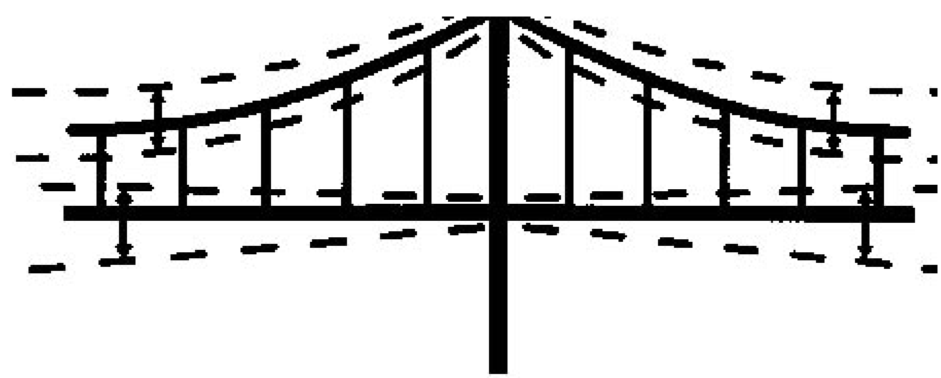


Figure 12.1.17 Cable Vibrations Global System Schematic

Effects of Vibrations

- Accelerates corrosion
- Opens cable wires allowing entry of corrosive chemicals
- Creates fretting
- Cracks grout
- Causes fatigue

John Roebling was the first to resolve the problem created by cable vibrations. His solution called for the use of diagonal cablestays (see Figure 12.1.18).

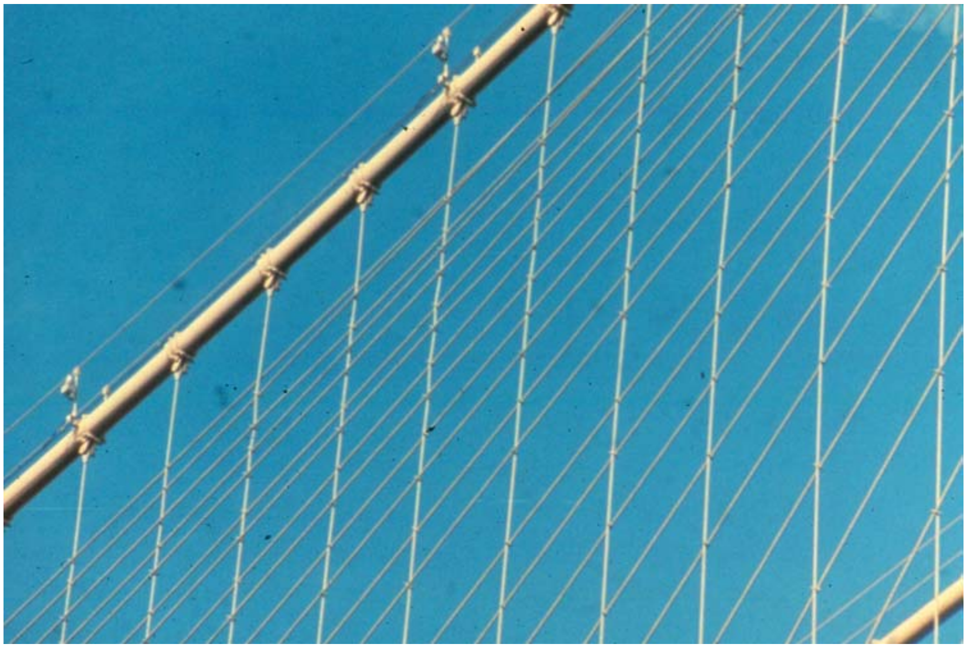


Figure 12.1.18 Close-up of Brooklyn Bridge Diagonal Cable-Stays

12.1.4 Cable-Stayed Bridges

Only the cable and its elements are described in this section. Refer to the appropriate section for detailed descriptions of other cable-stayed bridge members that are common to most structures.

Because of the complexity of the various cable arrangements and systems, fracture criticality for individual cable-stayed structures can only be determined through a detailed structural analysis.

Cable Arrangements and Systems

Cable-stayed bridges may be categorized according to the various longitudinal cable arrangements. These cable arrangements can be divided into the following four basic systems:

- Radial or Converging Cable System
- Harp Cable System
- Fan Cable System
- Star Cable System

Radial or Converging Cable System

In this system, all cables are leading to the top of the tower at a common point. Structurally, this arrangement is the most effective. By anchoring all the cables to the tower top, the maximum inclination to the horizontal is achieved (see Figure 12.1.19).

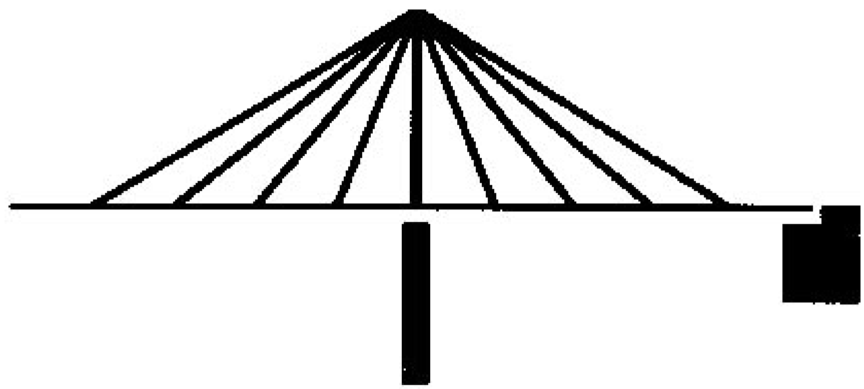


Figure 12.1.19 Radial or Converging Cable System Schematic

Harp Cable System

The harp system, as the name implies, resembles harp strings. In this system, the cables are parallel and equidistant from each other. The cables are also spaced uniformly along the tower height and connect to the deck superstructure at the same spacing (see Figure 12.1.20).

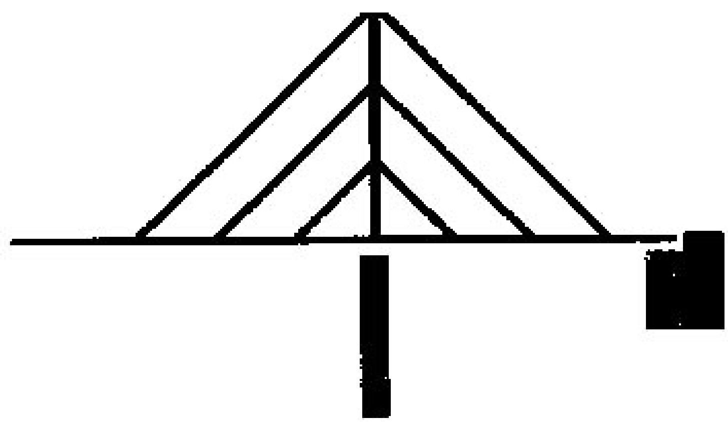


Figure 12.1.20 Harp or Parallel Cable System Schematic

Fan Cable System

The fan system is a combination of the radial and the harp systems. The cables emanate from the top of the tower at equal spaces and connect to the superstructure at larger equal spaces (see Figure 12.1.21).

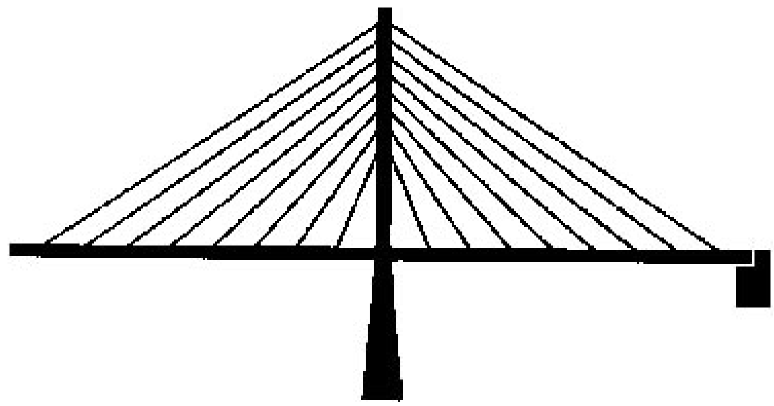


Figure 12.1.21 Fan or Intermediate Cable System Schematic

Star Cable System

In the star system, the cables intersect the tower at different heights and then converge on each side of the tower to intersect the deck structure at a common point. The common intersection in the anchor span is usually located over the abutment or end pier. The star system is rather uncommon. The star system requires a much stiffer deck structure since the cables are not distributed along the deck (see Figure 12.1.22).

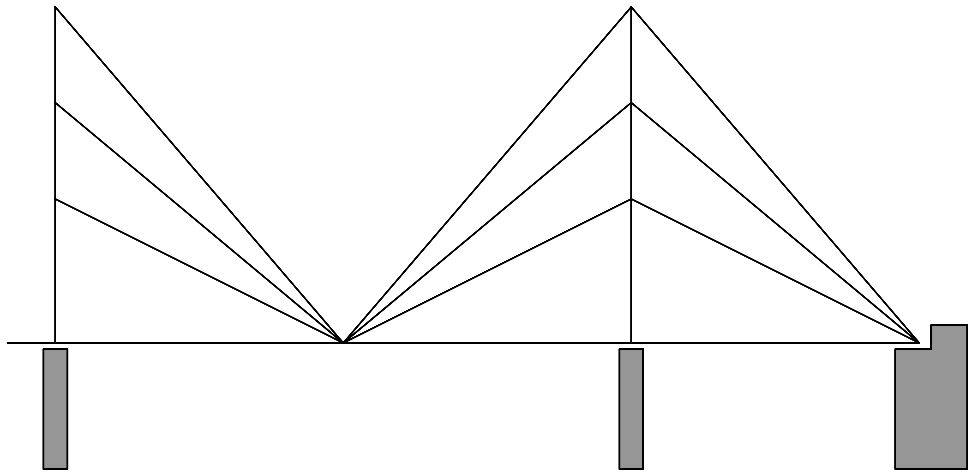


Figure 12.1.22 Star Cable System Schematic

Cable Planes

The cables may lie in either a single or a double plane, may be symmetrical or asymmetrical, and may lie in oblique or vertical planes.

Single Plane

The single-plane cable arrangement is used with a divided deck structure with the cables passing through the median area and anchored below the roadway. A single-plane cable system generally utilizes single towers (see Figure 12.1.23).

Figure 12.1.23 Single Vertical Plane Cable System

Double Vertical Plane

The double vertical plane system incorporates two vertical cable planes connecting the tower to the edge girders along the deck structure. The structure may utilize twin towers or a portal frame tower (see Figure 12.1.24). The portal frame tower is a twin tower with a connecting strut at the top. Wider bridges may utilize a triple plane system that is basically a combination of the single and double plane systems.

Figure 12.1.24 Double Vertical Plane Cable System

Double Inclined Plane

In this two plane system the cable planes are oblique, sloping toward each other from the edges of the roadway and intersecting at the tower along the longitudinal centerline of the deck (see Figure 12.1.25). Generally the tower is an A-frame type, receiving the sloping cables that intersect close to the roadway centerline on the tower.

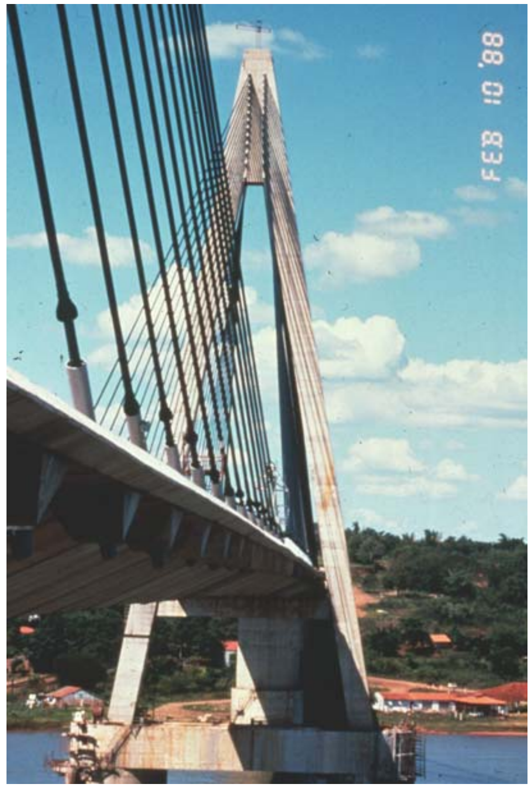


Figure 12.1.25 Double Inclined Plane Cable System

Types of Cables

Several types of cables have been used for cable-stayed bridges. The three most common are:

- Locked-coil strand
- Parallel wire
- Parallel seven-wire strand

The majority of existing cable-stayed bridges in the world, other than the United States, use preformed prestretched galvanized locked-coil strand. The cable-stayed bridges in the United States incorporate parallel wire or seven-wire prestressing strand in the cables, which are protected in a polyethylene tube filled with cement grout. The tube is commonly wrapped with a polyvinyl film.

Locked Coil Strand

This locked coil strand was previously shown for suspension bridges (refer back to Figure 12.1.11). Locked coil strand has not been used for bridges in this country. It is commonly used for cable-stayed bridges in Europe.

Parallel Wire

Parallel wire cables used in cable-stayed bridges conforms to ASTM A421, Type BA, low relaxation. It is basically stress-relieved wire used for prestressed concrete. Corrosion protection consists of polyethylene sheathing filled with cement grout. The tubing is usually wrapped with polyvinyl film tape (see Figure 12.1.26).

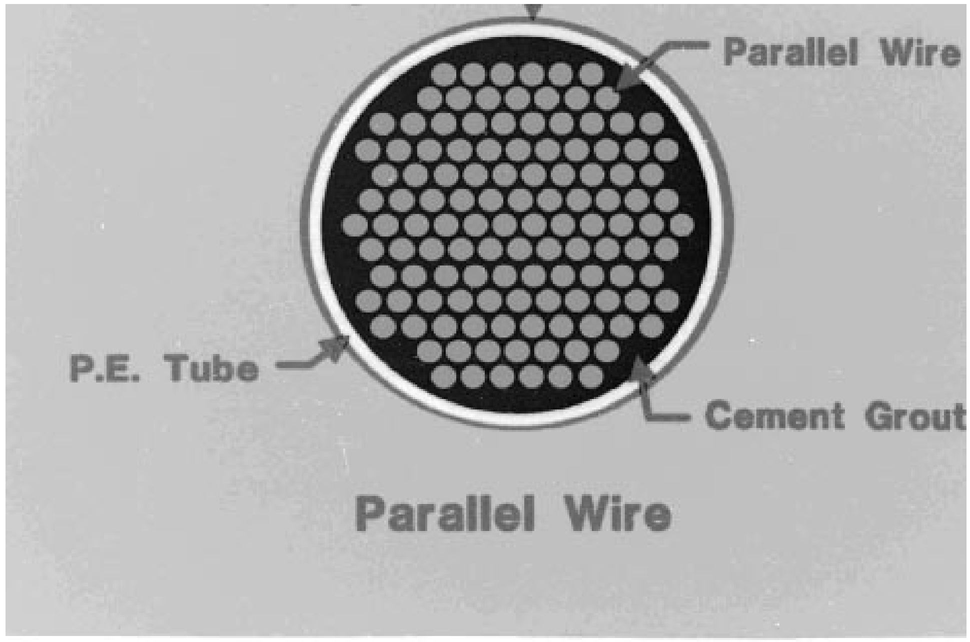


Figure 12.1.26 Parallel Wire

Parallel Strand

Seven-wire strand commonly used for cable-stayed bridges conforms to ASTM A416, weldless and low relaxation (see Figure 12.1.27). It is basically seven-wire stress-relieved strand for prestressed concrete. The corrosion protection system used for the seven-wire strand cables is similar to the system used for the parallel wire cables.

Figure 12.1.27 Parallel Strand

Anchorages and Connections

The cables may be continuous and pass through or over the tower or be terminated at the tower. If continuous across the tower, a saddle is incorporated.

Saddles

The cable saddles may be constructed from fabricated plates or steel castings with grooves through which the cables pass (see Figure 12.1.28). Between the end and center spans differential forces will occur at the cable saddles unless they are supported by rollers or rocker bearings. When the saddles are fixed, the rigidity of the system is at a maximum.

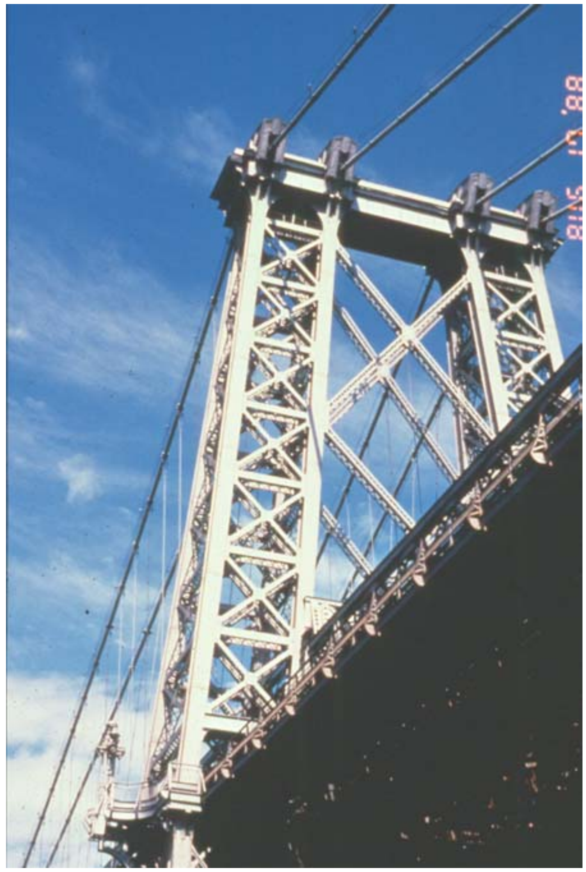


Figure 12.1.28 Cable Saddle

End Fittings

If terminated at the tower, an end fitting or anchorage is incorporated. A similar end fitting is utilized at the deck (see Figure 12.1.29).

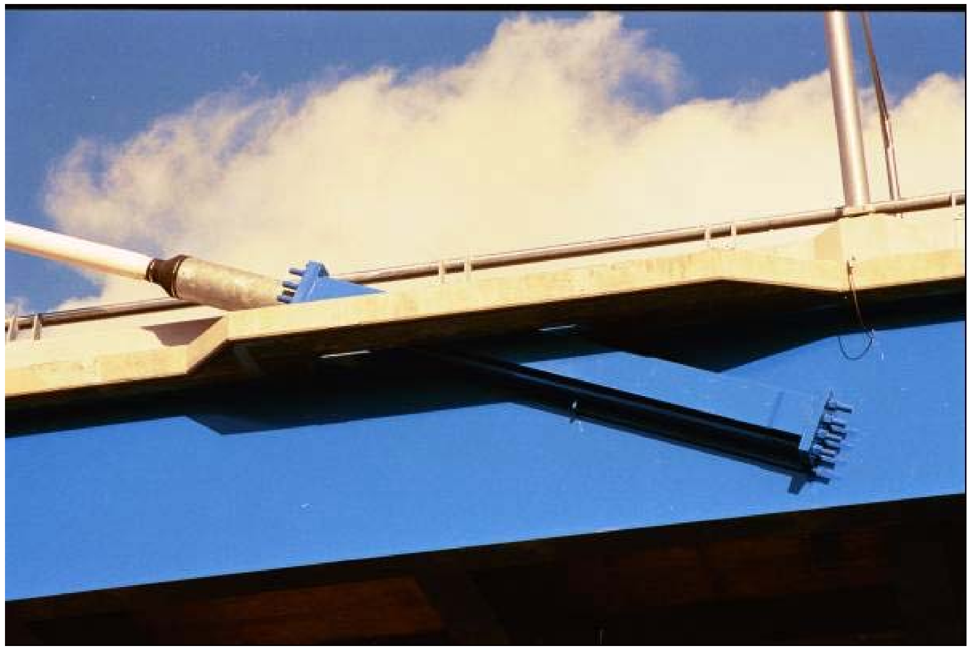


Figure 12.1.29 Cable Deck Anchorage

Socket

A socket widely used for the anchoring of parallel-wire strands is a poured zinc socket (see Figure 12.1.30). The wires are led through holes in a licking plate at the end of the socket and have the bottom heads providing the resistance against slippage of wires. The cavity inside the socket is filled with hot zinc alloys. To improve the fatigue resistance of the anchor, a cold casing material is used.

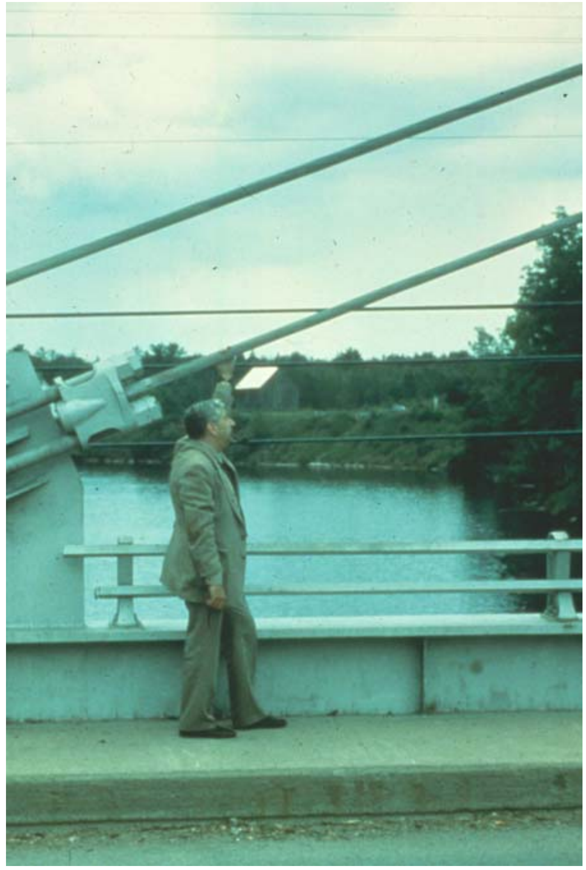


Figure 12.1.30 Parallel Wire Zinc-Filled Socket

The problems encountered with low fatigue strength of zinc-poured sockets lead to the development of HiAm sockets in 1968 for use with parallel wire stays.

This anchorage incorporates a flat plate with countersunk radial holes to accommodate the geometry of flared wires that transition from the compact wire bundle into the anchorage. The anchorage socket is filled with zinc dust and with an epoxy binder. This method of anchoring the stays increases the magnitude of fatigue resistance to almost twice that for the zinc-poured sockets.

A common anchorage type for strands is the Freyssinet type anchor.

In the Freyssinet socket the seven wire strand is anchored to an anchor plate using wedges similar to prestressing wedges. This wedge anchor is used during erection. After application of dead load the anchor tube is filled with an epoxy resin, zinc dust, and steel ball composition. Under live load, the additional cable force will be transformed by shear from the cable strand to the tube.

Types of Towers

- Portal tower
- A-frame tower
- Single tower

Towers are constructed of reinforced concrete or steel or a combination of the two (see Figure 12.1.31 and 12.1.32).

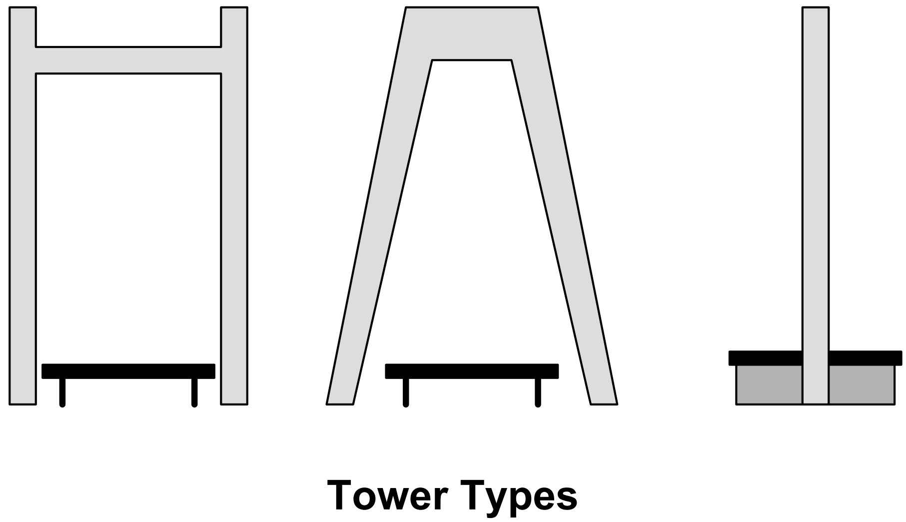


Figure 12.1.31 Tower Types Schematic

Figure 12.1.32 Inside of a Concrete Portal Tower

The deck structures are also constructed of concrete or steel.

12.1.5 Overview of Common Defects

Common defects that can occur on the cable members of a cable-supported bridge include:

- Failure of the Paint System
- Pitting
- Surface Rust
- Section Loss
- Fatigue Cracking

- Collision Damage
- Overload Damage
- Heat Damage

Refer to Topic 2.3 for a more detailed presentation of the properties of steel, types and causes of steel deterioration, and the examination of steel.

12.1.6 Inspection Locations and Procedures for Suspension Bridge Cable System Elements

The inspection and maintenance procedures presented in this Topic are not exhaustive, but are unique to the particular bridge type. Therefore, the inspection of special bridges should include both those procedures presented in this Topic and the general procedures presented previously in this manual.

Due to the specialized nature of these bridges and because no two cable supported bridges are identical, the inspection should be led by someone very familiar with the particular bridge. Many major bridges, such as cable supported bridges, will have individual maintenance manuals developed specifically for that bridge, like an "owner's" manual. If available, the inspector should use this valuable tool throughout the inspection process and should verify that specified routine maintenance has been performed. Customized, preprinted inspection forms should be used wherever possible to enable the inspector to report the findings in a rigorous and systematic manner.

Main Cable Anchorage Elements

The anchorage system, at the ends of the main cables, consists of a number of elements that require inspection (see Figure 12.1.33).

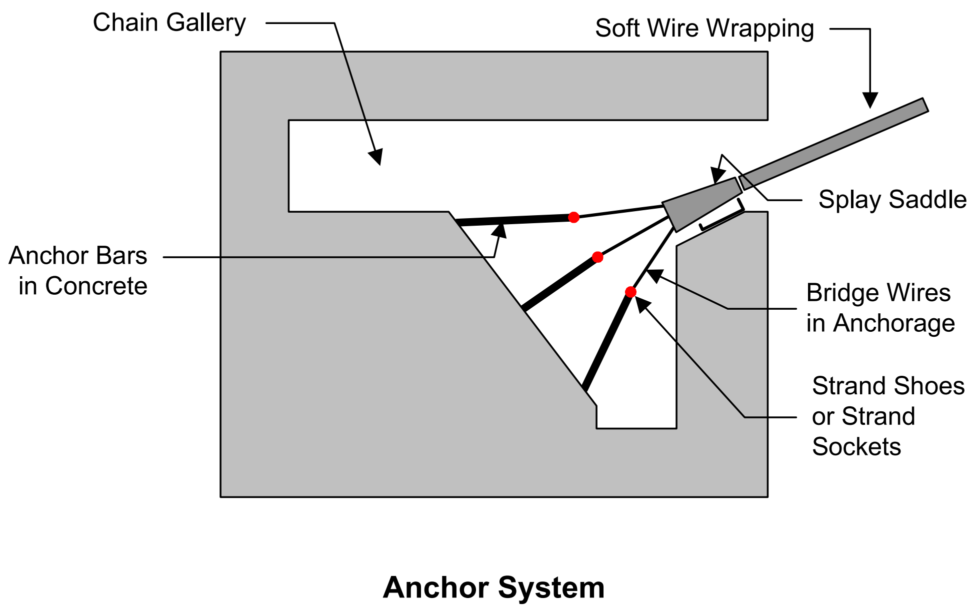


Figure 12.1.33 Schematic Slide Anchorage System

Splay Saddle

Inspect the splay saddles for:

- Missing or loose bolts
- Movement up the cable away from the splay; signs of this movement may be the appearance of unpainted strands on the lower side or "bunched up" wrapping on the upper side
- The presence of cracks in the casting itself

Wires in Anchorage

In parallel wire type suspension bridges, inspect the unwrapped wires between the strand shoes and the splay saddle. Carefully insert a large screwdriver between the wires and apply leverage. This will help reveal broken wires. Inspect the wires for:

- Abrasion damage
- Corrosion
- Movement.

Strand Shoes or Sockets

At the anchorages of parallel wire type suspension bridges, inspect the strand shoes for:

- Signs of displaced shims, along with movement, corrosion, misalignment, and cracks in the shoes

At the anchorages of prefabricated strand type suspension bridges, inspect the strand sockets for:

- Signs of movement
- Slack or sag
- Corrosion
- Broken sockets
- Unpainted or rusty threads at the face of the sockets; this may indicate possible "backing off" of nuts.

Anchor Bars

Inspect the anchor bars or rods for:

- Corrosion, deterioration, or movement at the face of their concrete embedment
- Corrosion or other signs of distress over the entire visible (unencased) portion

Anchorage Interior

Inspect the interior of the anchorage for:

- Corrosion and deterioration of any steel hardware
- Protection against water entering or collecting where it may cause corrosion
- Proper ventilation
- Cracks and spalls in the concrete anchor

Main Suspension Cables

The main suspension cables should be inspected as follows:

Locations

Inspect the main suspension cables for indications of corroded wires. Inspect the condition of the protective covering or coating, especially at:

- Low points of cables
- Areas adjacent to the cable bands
- Saddles over towers
- Anchorages

Cable Wrapping

Inspect the wrapping wire for:

- Cracks, staining, and dark spots (see Figure 12.1.34)
- Loose wrapping wires
- Cracks in the caulking where water can enter and cause corrosion of the main suspension cable
- Evidence of water seepage at the cable bands, saddles, and splay castings

Figure 12.1.34 Staining on Cable Wrap Indicating Internal Problems

Hand Ropes

Inspect the hand ropes and connections along the main cables for:

- Loose connections of stanchion to cable bands
- Too much slack in rope
- Bent or twisted stanchions (hand rope supports)
- Loose connections at anchorages or towers
- Corroded or deteriorated ropes or stanchions

Vibration

- Note and record all excessive vibrations.

Saddles

Inspect the saddles for:

- Missing or loose bolts
- Slippage of the main cable
- Corrosion or cracks in the casting
- Proper connection to top of tower or supporting member

Suspender Cables and Connections

Inspect the suspender cables for:

- Corrosion or deterioration
- Kinks or slack
- Abrasion or wear at sockets, saddles, clamps, and spreaders
- Broken wires
- Excessive vibrations

Sockets

Inspect the suspender rope sockets for:

- Corrosion, cracks, or deterioration
- Abrasion at connection to bridge superstructure
- Possible movement

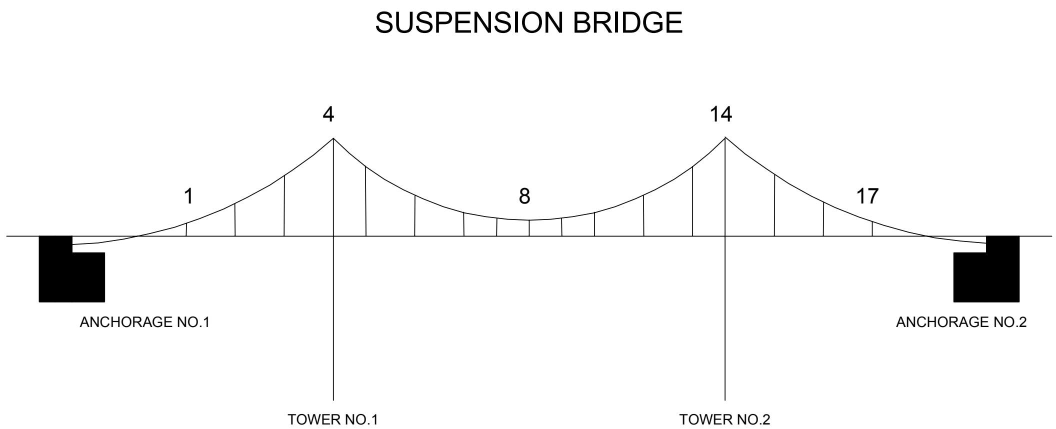
Cable Bands

Inspect the cable bands for:

- Missing or loose bolts
- Possible slippage; signs of this movement are caulking that has pulled away from the casting or "bunching up" of the soft wire wrapping adjacent to the band
- The presence of cracks in the band itself
- Broken suspender saddles
- Corrosion or deterioration of the band
- Loose wrapping wires at the band

Recordkeeping and Documentation

A set of customized, preprinted forms should be prepared for documenting all defects encountered in the cable system of a suspension bridge. A suggested sample form is presented in Figure 12.1.35. A separate form should be used for each main suspension cable. Designations used to identify the suspender ropes and the panels provide a methodology for locating the defects in the structure.



SUSPENDER CABLE CONDITION

1.	7.	13.
2.	8.	14.
3.	9.	15.
4.	10.	16.
5.	11.	17.
6.	12.	

Figure 12.1.35 Form for Recording Defects in the Cable System of a Suspension Bridge

12.1.7 Inspection Locations and Procedures for Cable-Stayed Bridge Cable System Elements

A cable-stayed bridge is a bridge in which the superstructure is supported by cables, or stays, passing over or attached directly to towers located at the main piers (see Figure 12.1.36 and 12.1.37). There are several special elements that are unique to cable-stayed bridges, and the bridge inspector should be familiar with them.

Figure 12.1.36 Cable-Stayed Bridge

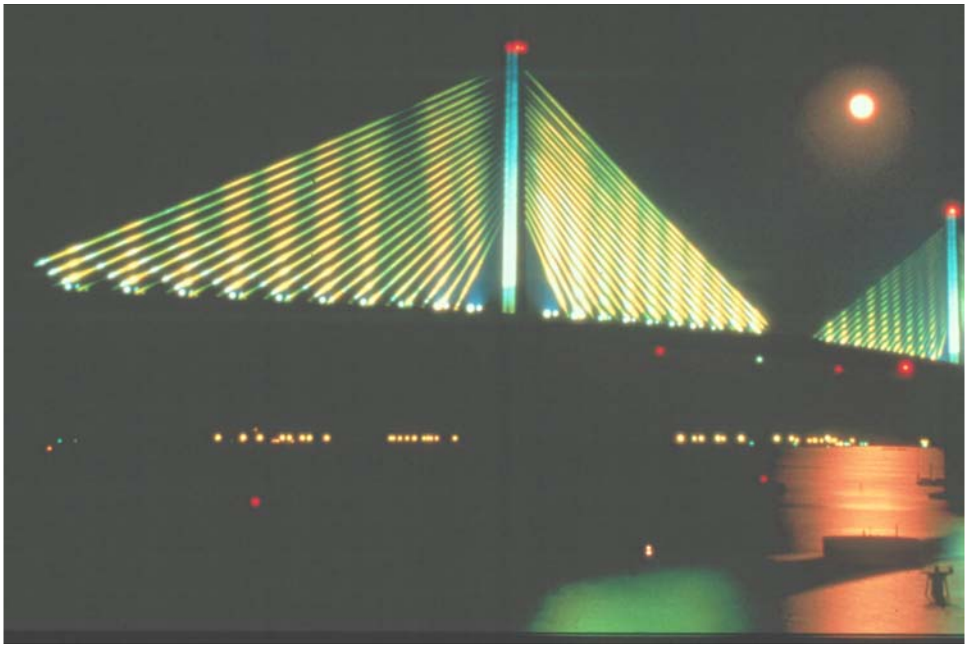


Figure 12.1.37 Cable-Stayed Bridge Cables

Inspection Elements

The inspection of the cable elements should include:

- Cable wrappings and wrap ends near the tower and deck
- Cable sheathing assembly
- Dampers
- Anchorages

Cable Wrapping

Common wrapping methods for corrosion protection of finished cables include spirally wound soft galvanized wire, neoprene, or plastic wrap type tape (see Figure 12.1.38). The wrappings should be inspected for:

- Corrosion and cracking of soft galvanized wire
- Staining and dark spots indicating possible corrosion of the cables
- Bulging or deforming of wrapping material indicating possible broken wire (see Figure 12.1.39)
- Loose wrapping wires or tape
- Evidence of water seepage at the cable bands, saddles, and splay castings

Figure 12.1.38 Cable Wrapping Placement

Figure 12.1.39 Investigation of Deformed Cable Wrapping

Cable Sheathing Assembly

The most common types of cable sheathing assemblies are steel sheathing and polyethylene sheathing.

Steel Sheathing

If steel sheathing is used, inspect the system for:

- Corrosion (see Figure 12.1.40)
- Condition of Protective coatings
- Bulging which may indicate broken wires (see Figure 12.1.41).
- Splitting which may be caused by water infiltration and corrosive action.
- Cracking which is sometimes caused by fatigue (see Figure 12.1.42).
- Weld fusion

Polyethylene Sheathing

If polyethylene sheathing is used, inspect the system for:

- Nicks, cuts, and abrasions
- Cracks and separations in caulking
- Cracks and separations in fusion welds
- Bulging which may indicate broken wires (see Figure 12.1.41).
- Splitting which is sometimes caused by temperature fluctuations (see Figure 12.1.43). Coefficient of the thermal expansion for polyethylene is three times higher than the value for steel or concrete.
- Cracking which is sometimes caused by fatigue

Figure 12.1.40 Corrosion of Steel Sheathing

Figure 12.1.41 Bulging of Cable Sheathing

Figure 12.1.42 Cracking of Cable Sheathing

Figure 12.1.43 Splitting of Cable Sheathing

Dampers

Shock Absorber Type

A variety of damper types may have been installed (see Figure 12.1.44 and 12.1.45). If shock absorber type dampers are used, inspect the system for:

- Corrosion
- Tightness in the connection to the cable pipe
- Oil leakage in the shock absorbers

- Deformations in the bushings
- Torque in the bolts

Figure 12.1.44 Shock Absorber Damper System

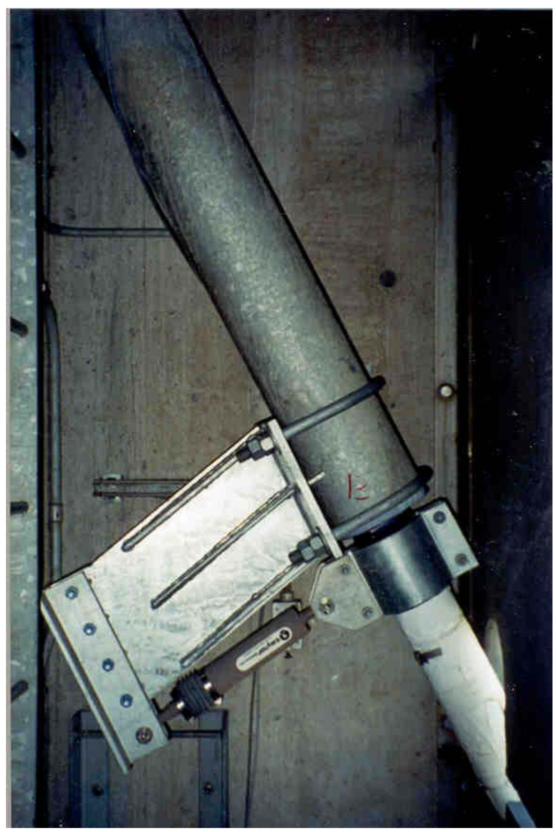


Figure 12.1.45 Shock Absorber Damper System

Tie Type

Inspect the tie type dampers for (see Figure 12.1.46):

- Corrosion
- Tightness in the connection to the cable pipe
- Deformations in the bushings
- Torque in the bolts

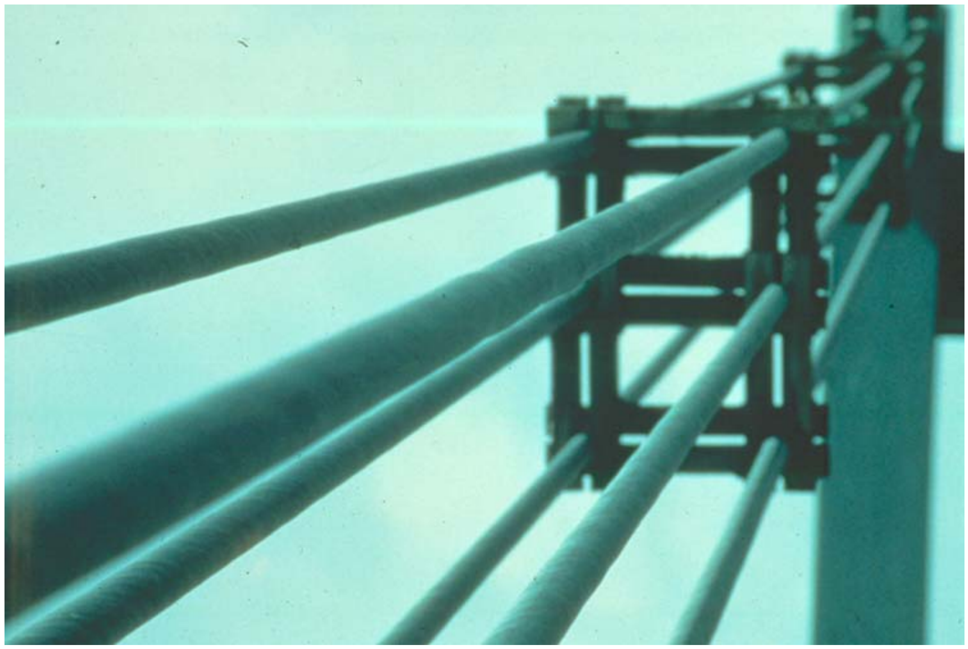


Figure 12.1.46 Cable Tie Type Damper System

Tuned Mass Type

Inspect the tuned mass dampers for (see Figure 12.1.47):

- Corrosion
- Tightness in the connection to the cable pipe
- Deformations in the bushings
- Torque in the bolts

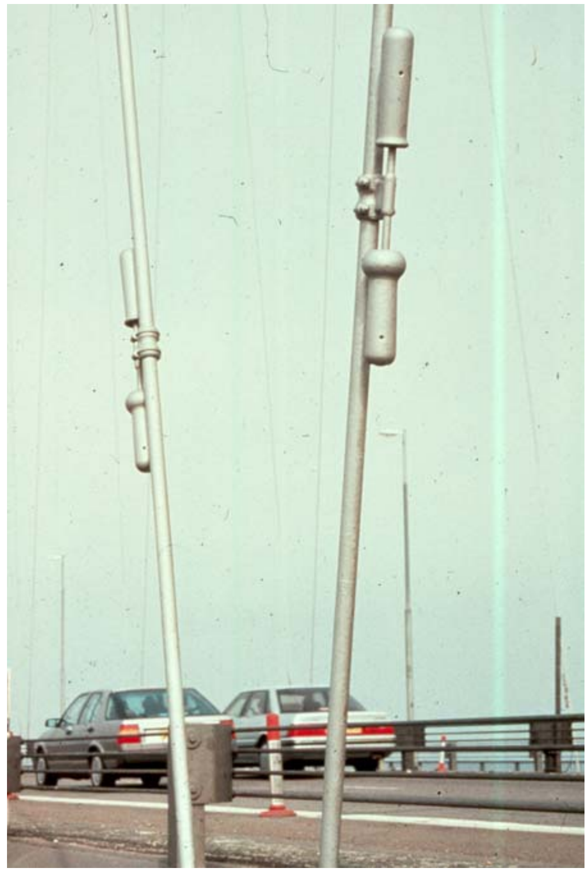


Figure 12.1.47 Tuned Mass Damper System

Anchorages

End Anchorage

Inspect the transition area between the steel anchor pipe and cable for:

- Water tightness of neoprene boots at the upper ends of the steel guide pipes (see Figure 12.1.48)
- Drainage between the guide pipe and transition pipe
- Defects, such as splits and tears, in the neoprene boots
- Sufficient clearance between the anchor pipe and cable, noting rub marks and kinks

Figure 12.1.48 Neoprene Boot at Steel Anchor Pipe Near Anchor

Tower Anchorage

Inspect the cable anchorages for:

- Corrosion of the anchor system (see Figure 12.1.49)
- Cracks and nut rotation at the socket and bearing plate
- Seepage of grease from the protective hood

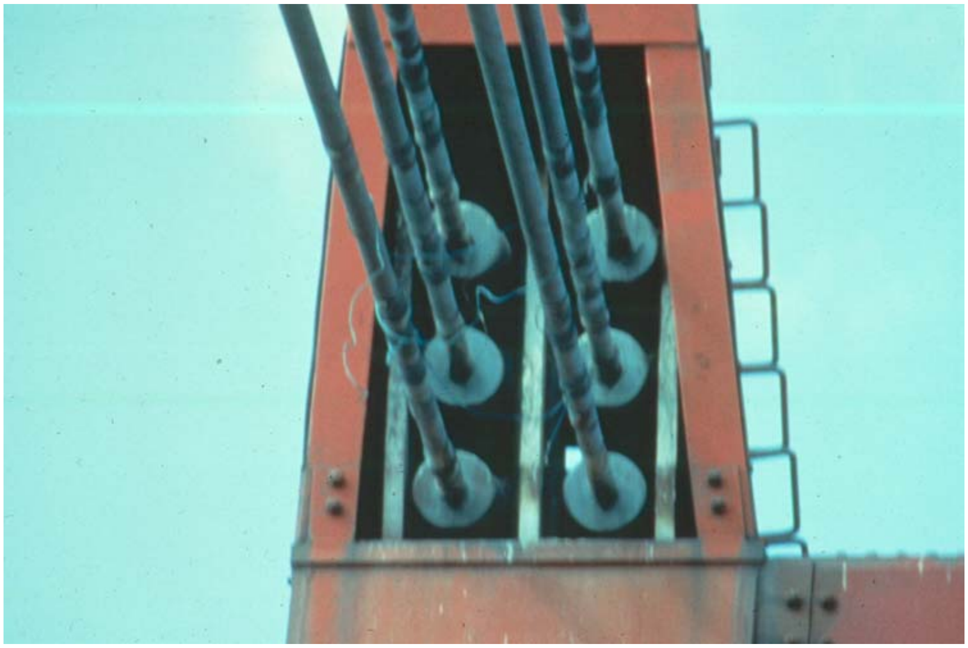


Figure 12.1.49 Corrosion of the Anchor System

Other Inspection Items

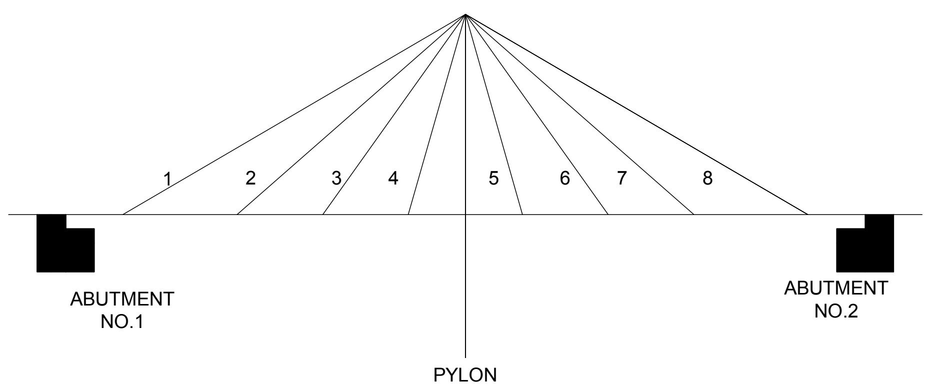
The inspection of the cable system should also include:

- Anchor pipe clearances
- Flange joints
- Polyethylene expansion joints
- Reading the load cells and recording the forces
- Noting and recording all excessive vibrations including amplitude and type of vibration along with wind speed and direction, or other forces including vibrations such as traffic.
- Cable lighting

Recordkeeping and Documentation

A set of customized, preprinted forms should be prepared for documenting all defects encountered in the cable system of a cable-stayed bridge. A suggested sample form is presented in Figure 12.1.50. A separate form should be used for each plane or set of cables. Designations used to identify the cables and the panels provide a methodology for locating the defects in the structure.

CABLE-STAYED BRIDGE



SUSPENDER CABLE CONDITION

1.	5.
2.	6.
3.	7.
4.	8.

Figure 12.1.50 Form for Recording Defects in Cable System of a Cable-Stayed Bridge

12.1.8 Advanced Inspection Techniques

In bridge cables, whether a suspension bridge or cable-stayed bridge, the greatest problems generally occur due to corrosion and fracture of individual wires. Visual inspection of unwrapped cables is limited to the outer wires, while visual inspection of wrapped cables is limited to the protective sheathing. Therefore, advanced inspection techniques should be used to achieve a more rigorous and thorough inspection of the cables, including:

- Magnetic induction
- Electrical resistivity

- Dye penetrant
- Ultrasonic testing
- Radiographic testing
- Acoustic emission
- Accelerometers
- Strain measurements
- Vibration measurements
- Magnetic flux leakage
- Measurement of loads
- Measurement of stress ranges

See Section 13.3 for Advanced Inspection Techniques.

12.1.9 Evaluation

State and federal rating guidelines systems have been developed in order to aid in the inspection of steel superstructures. The two major rating guidelines systems currently in use include the National Bridge Inspection Standards (NBIS) rating and the Bridge Management System (BMS).

Application of the NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0 where 9 is the best rating possible. See Section 4.2.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the cables. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element Level Smart Flags are also used to describe the condition of the steel superstructure both unpainted and painted.

In an element level condition state assessment of a cable-supported bridge, the AASHTO CoRe element is:

Element No.	Description
146	Unpainted Steel Cable (not embedded in concrete)
147	Painted Steel Cable (not embedded in concrete)

The unit quantity for cables is each and the total number of cables must be placed in one of the four available condition states for unpainted and five available condition states for painted. In both cases, Condition State 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to fatigue, the "Steel Fatigue" Smart Flag, Element No. 356, can be used and one of the three condition states assigned. For rust, the "Pack Rust" Smart Flag, Element No. 357, can be used and one of the four condition states assigned. For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned. For cables with section loss, the "Section Loss" Smart Flag, Element No. 363, can be used and one of the four condition states assigned.

Table of Contents

Section 12
Special Bridges

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Topic 12.2 Movable Bridges

12.2.1 Introduction

This section serves as an introduction to the highly specialized area of movable bridge inspection (see Figure 12.2.1). It focuses on the types of movable bridges and special elements associated with the various types.

Figure 12.2.1 Movable Bridge

Movable bridges are normally constructed only when fixed bridges are either too expensive or impractical. Movable bridges are constructed across designated "Navigable Waters of the United States," in accordance with "Permit Drawings" approved by the U.S. Coast Guard. When a movable bridge is fully open, it must provide the channel width and the underclearance shown on the Permit Drawings (see Figure 12.2.2). If the bridge cannot be opened to provide these clearances, the U.S. Coast Guard should be notified immediately and action taken to restore the clearances. If that is impossible, application must be made to revise the Permit Drawings.

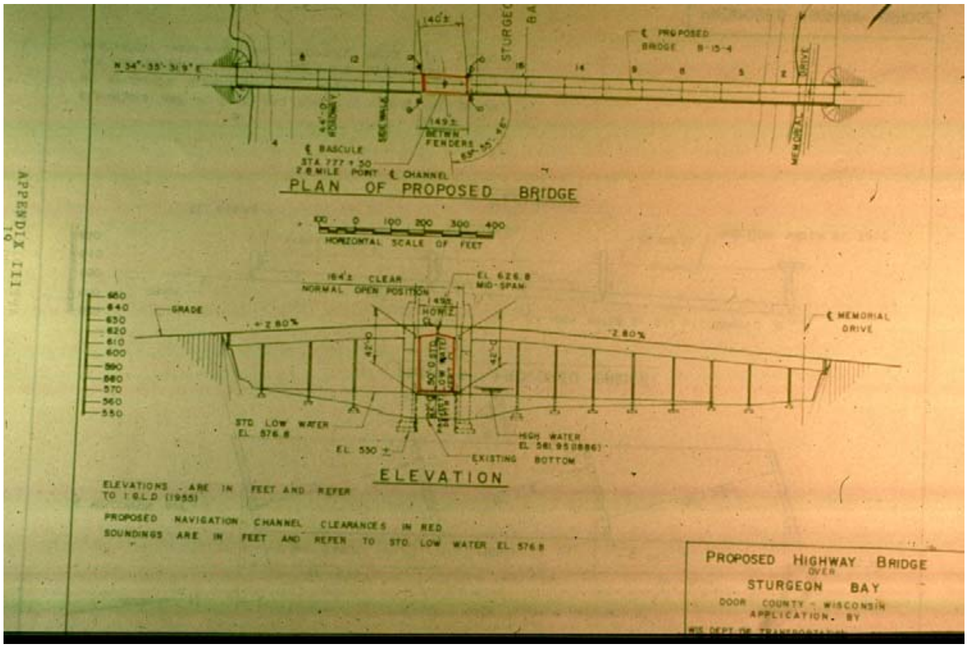


Figure 12.2.2 Typical "Permit Drawing" Showing Channel Width and Underclearance, Both Closed and Open, that Must be Provided

If any work is to be done in the channel or on the movable span to reduce the clearances from those shown on the Permit Drawing, an additional permit, covering the scheduled time for the work, must be obtained from the U.S. Coast Guard District that has jurisdiction.

The U.S. Coast Guard publishes Local Notices to Mariners to keep waterway users informed of work in progress that may affect navigation. The permittee must keep the U.S. Coast Guard informed of all stages of construction.

An inspection of the bridge should verify that the bridge conforms to the Permit Drawing and that the operator is instructed to open the bridge to the fully open position every time the bridge is operated. Failure to do this would establish a precedent that a vessel is expected to proceed before the green navigation lights have turned "on." Any accident caused as a result of this practice could be ruled the fault of the bridge owner.

Early America's engineering literature did not establish where the first iron drawbridge was built. The first all-iron movable bridge in the Midwest was completed in 1859 carrying Rush Street over the Chicago River (see Figure 12.2.3). The bridge was a rim bearing swing span and was probably operated by steam. It was destroyed November 3, 1863 when it was opened while a drove of cattle was on one end. It was rebuilt and finally destroyed by the great Chicago fire of 1871.

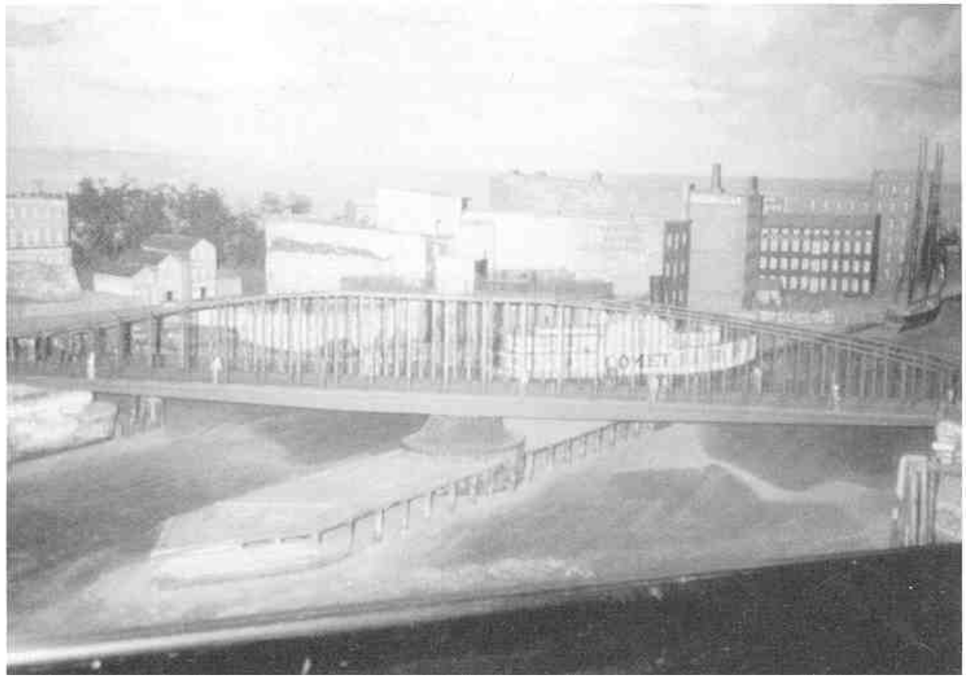


Figure 12.2.3 The First All-Iron Movable Bridge in the Midwest was Completed in 1859 (Photo on File at the Chicago Historical Society

All categories of movable bridges are powered by electric-mechanical or hydraulic-mechanical drives with power driven pinions operating against racks, or by hydraulic cylinders. A small number are hand powered for normal operation, and a few use it for standby operation. Three categories of movable bridges comprise over 95 percent of the total number of movable bridges within the United States. These categories are:

- Swing bridges
- Bascule bridges
- Vertical lift bridges

12.2.2
Swing Bridges Design Characteristics

Swing bridges consist of two-span trusses or continuous girders, which rotate horizontally about the center (pivot) pier (see Figure 12.2.4). The spans are usually, but not necessarily, equal. When open, the swing spans are cantilevered from the pivot (center) pier and must be balanced longitudinally and transversely about the center. When closed, the spans are supported at the pivot pier and at two rest (outer) piers or abutments. In the closed condition, wedges are usually driven under the outer ends of the bridge to lift them, thereby providing a positive reaction sufficient to offset any possible negative reaction from live load and impact in the other span. This design feature prevents uplift and hammering of the bridge ends under live load conditions.

Figure 12.2.4 Center-Bearing Swing Bridge

Swing spans are subdivided into two types:

- Center-bearing
- Rim-bearing

Center-Bearing

Center-bearing swing spans carry the entire load of the bridge on a central pivot (usually metal discs). Balance wheels are placed on a circular track around the outer edges of the pivot pier to prevent tipping (see Figures 12.2.5 and 12.2.6). When the span is closed, wedges similar to those at the rest piers are driven under each truss or girder at the center pier. This relieves the center bearing from carrying any live load. However, these wedges should not raise the span at the pivot pier, but should merely be driven tight.

The latest swing spans built are nearly all of the center-bearing design. Center-bearing swing spans are less complex and less expensive to build than rim-bearing swing spans.

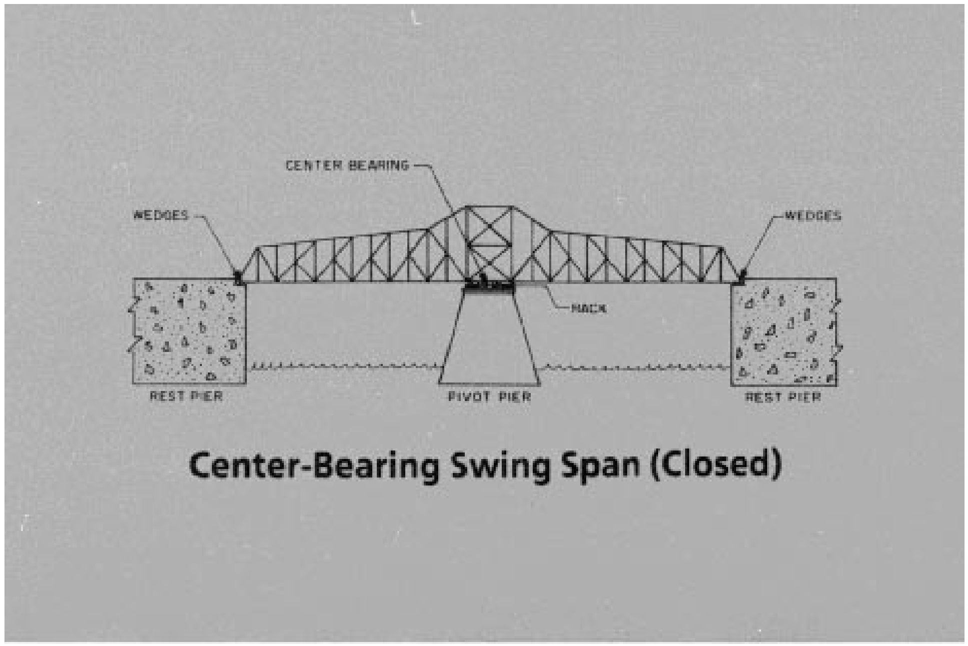


Figure 12.2.5 Center-Bearing Swing Span in Closed Position

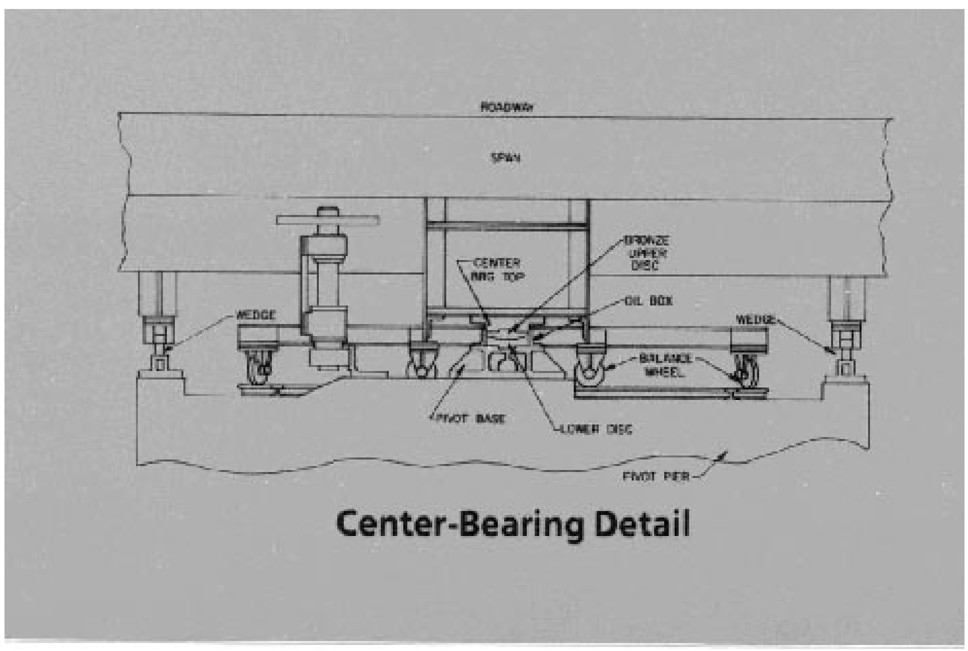


Figure 12.2.6 Layout of Center-Bearing Type Swing Span with Machinery on the Span

Rim-Bearing

Rim-bearing swing spans transmit all loads, both dead and live, to the pivot pier through a circular girder or drum to beveled rollers. The rollers move on a circular track situated inside the periphery of the pier. The rollers are aligned and spaced on the track by concentric spacer rings. This type of swing span bridge also has a central pivot bearing which carries part of the load. This pivot bearing is connected to the rollers by radial roller shafts and keeps the span centered on the circular track.

On both types of swing bridges, the motive power is usually supplied by an electric motor(s), hydraulic motor(s), or hydraulic cylinder(s), although gasoline engines or manual power may also be used. The bridge is rotated horizontally by a circular rack and pinion arrangement, or cylinders.

12.2.3 Bascule Bridges Design Characteristics

Bascule bridges open by rotating a leaf or leaves (movable portion of the span) from the normal horizontal position to a point that is nearly vertical, providing an open channel of unlimited height for marine traffic (see Figure 12.2.7).

Figure 12.2.7 Bascule Bridge in the Open Position

If the channel is narrow, a single span may be sufficient. This is called a single-leaf bascule bridge. For wider channels, two leaves are used, one on each side of the channel. When the leaves are in the lowered position, they meet at the center of the channel. This is known as a double-leaf bascule bridge.

A counterweight is necessary to hold the raised leaf in position. In older bridges, the counterweight is usually overhead, while in more modern bascule bridges, the counterweight is placed below the deck and lowers into a pit as the bridge is opened.

The leaf lifts up by rotating vertically about a horizontal axis. The weight of the counterweight is adjusted by removing or adding balance blocks in pockets to position the center of gravity of the moving leaf at the center of rotation. When the bridge is closed, a forward bearing support located in front of the axis is engaged and takes the live load reaction. On double-leaf bascule bridges, a tail-lock behind the axis and a shear lock at the junction of the two leaves are also engaged to stiffen the deck.

There are many types of bascule bridges, but the most common are the following three types:

- Rolling lift (Scherzer) bridge
- Simple trunnion (Chicago) bridge
- Multi-trunnion (Strauss) bridge

Rolling Lift (Scherzer) Bridge

The first rolling lift bridge, completed in January 1895 in Chicago, was designed by William Scherzer. The entire moving leaf, including the front arm with the roadway over the channel and the rear arm with the counterweight, rolls away from the channel while the moving leaf rotates open (see Figure 12.2.8). On this type of bridge, curved tracks are attached to each side of the tail end of the leaf. The curved tracks roll on flat, horizontal tracks mounted on the pier. Square or oblong holes are machined into the curved tracks. The horizontal tracks have lugs (or teeth) to mesh with the holes preventing slippage as the leaf rolls back on circular castings whose centerline of roll is also the center of gravity of the moving leaf. Double-leaf bascule bridges are also constructed (see Figure 12.2.9).

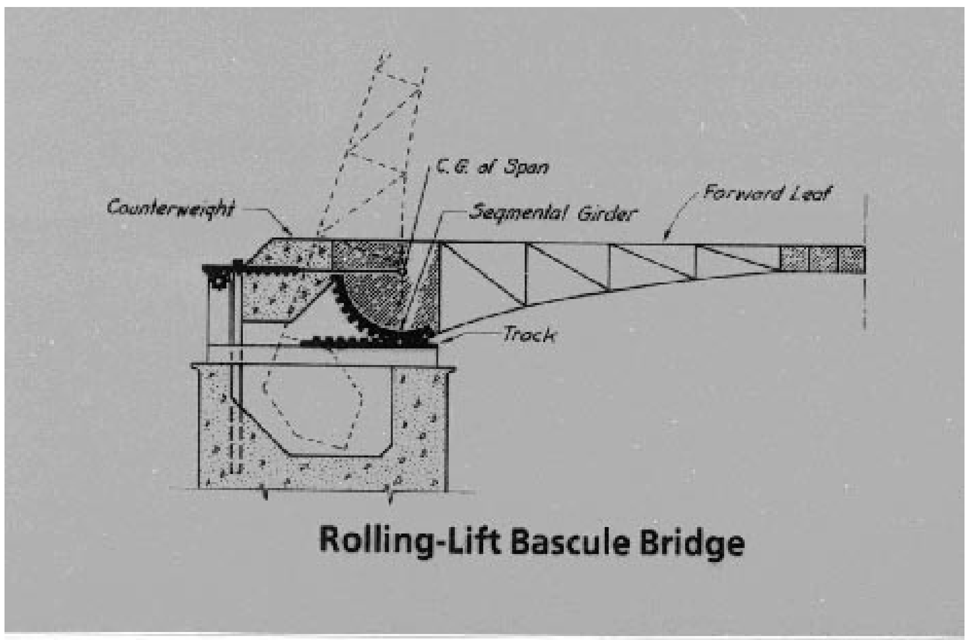


Figure 12.2.8 Rolling Lift Bascule Bridge Schematic

Figure 12.2.9 Double-Leaf Rolling Lift Bascule

The simple principal of this type of bridge can be seen easiest with a railroad bridge. The dead load of the bridge is balanced about the centerline of the drive pinion (center of roll). The pinion teeth are engaged with the teeth on the rack casting. When the pinion turns it moves along on the fixed rack and causes the span to rotate on the circular tread casting as it rolls back on the track casting.

The weight of the leaf, including the superstructure and counterweight, is supported by the curved tracks resting on the horizontal tracks. The counterweight is positioned to balance the weight of the leaf.

On one variation of this type, the trusses on the two leaves acted as three-hinged arches when closed. There is a 310 feet (94.5 m) span between the centerline of bearings. This bridge was built across the Tennessee River at Chattanooga in 1915, and it is believed to be the third longest double-leaf bascule in the world. It provides a 295-foot (89.9 m) channel, which is the widest channel spanned by a bascule bridge.

Simple Trunnion (Chicago) Bridge

The Chicago Bridge Department staff of Engineers designed the first Chicago type simple trunnion bascule bridge, completed during 1902. This type of bascule bridge consists of a forward cantilever arm out over the channel and a rear counterweight arm (see Figure 12.2.10). The leaf rotates about the trunnions. Each trunnion is supported on two bearings, which in turn, are supported on the fixed portion of the bridge such as a trunnion cross-girder, steel columns, or on the pier itself (see Figures 12.2.11, 12.2.12, 12.2.13). Forward bearing supports located in front of the trunnions are engaged when the leaf reaches the fully closed position. They are intended to support only live load reaction. Uplift supports are located behind the trunnions to take uplift until the forward supports are in contact (if misadjusted) and to take the live load uplift that exceeds the dead load reaction at the trunnions. If no forward live load supports are provided or if they are grossly misadjusted, the live load and the reaction at the uplift supports are added to the load on the trunnions. A double-leaf bascule bridge of this type in Lorain, Ohio has101.5 m (333 feet) between trunnions. It was built on a skewed crossing of a river, and it is believed to be the second longest double-leaf bascule in the world. Of the three types of movable bridges, the simple trunnion is by far the most popular.

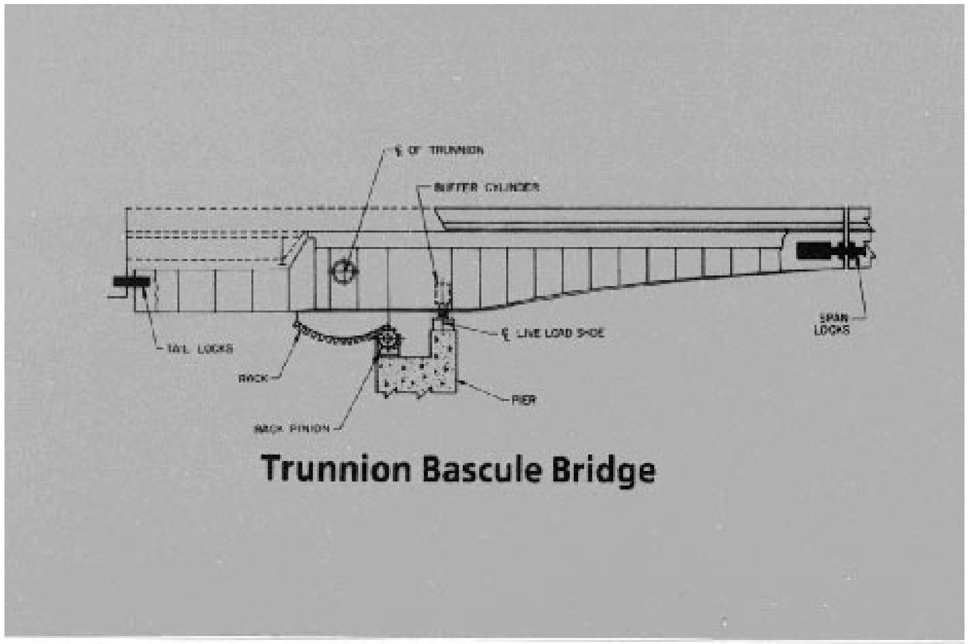


Figure 12.2.10 Trunnion Bascule Bridge Schematic

Figure 12.2.11 Double-Leaf Trunnion Bascule Bridge

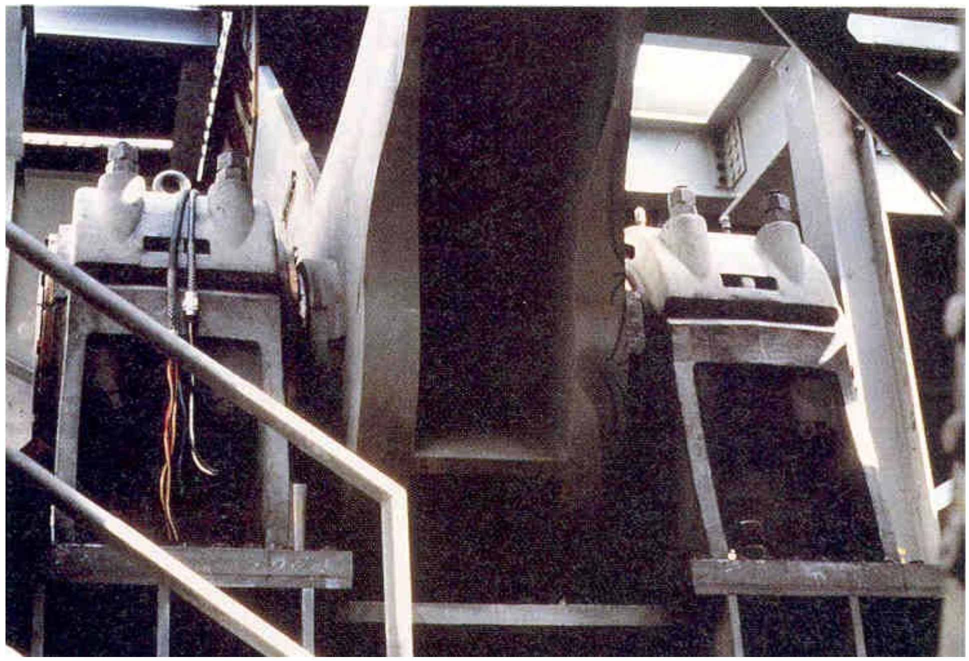


Figure 12.2.12 Each Trunnion is Supported on Two Bearings, Which in Turn are Supported on a Fixed Cross-Girder

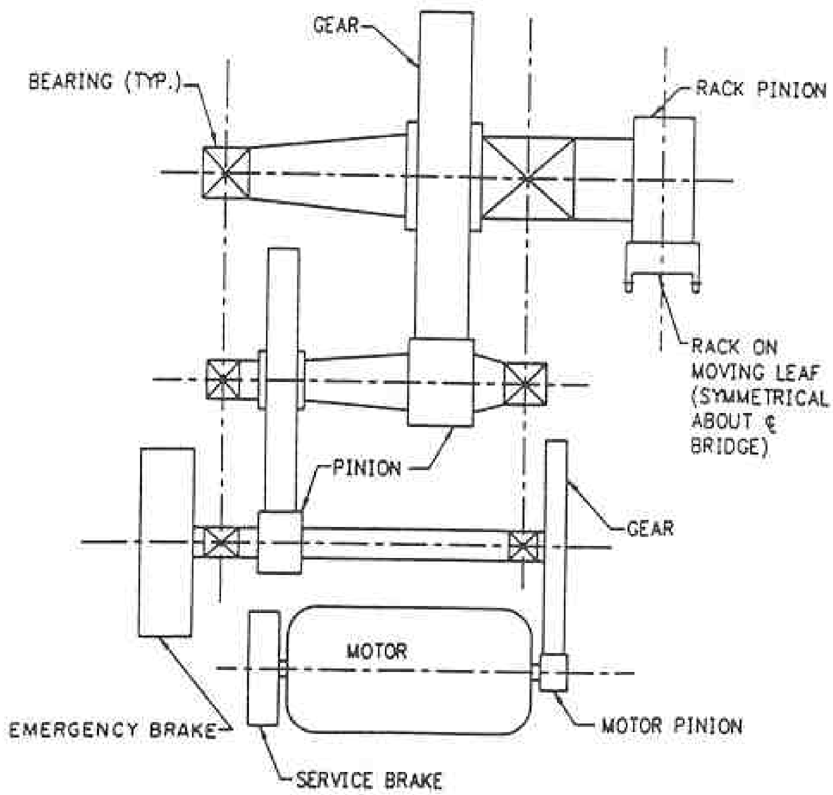


Figure 12.2.13 The Trunnion Bascule Bridge Machinery (One Quarter Shown) is Located Outside of the Bascule Trusses on the Pier; the Leaf Rotates about the Centerline on the Trunnions

Multi-Trunnion (Strauss Bridge)

The first multi-trunnion (Strauss) bascule bridge was designed by J.B. Strauss and completed during 1905 in Cleveland, Ohio. There are many variations of multi-trunnion bascule bridges, but basically one trunnion supports the moving span, one trunnion supports the counterweight, and two link pins are used to form the four corners of a parallelogram-shaped frame that changes angles as the bridge is operated (see Figure 12.2.14). One variation of this parallelogram layout is the heel trunnion. A double-leaf bascule bridge of this type in Sault St. Marie, Michigan has 336 feet (102.4 m) between the span trunnions. It was built across the approach to a lock in 1914, and it is believed to be the longest double-leaf bascule in the world.

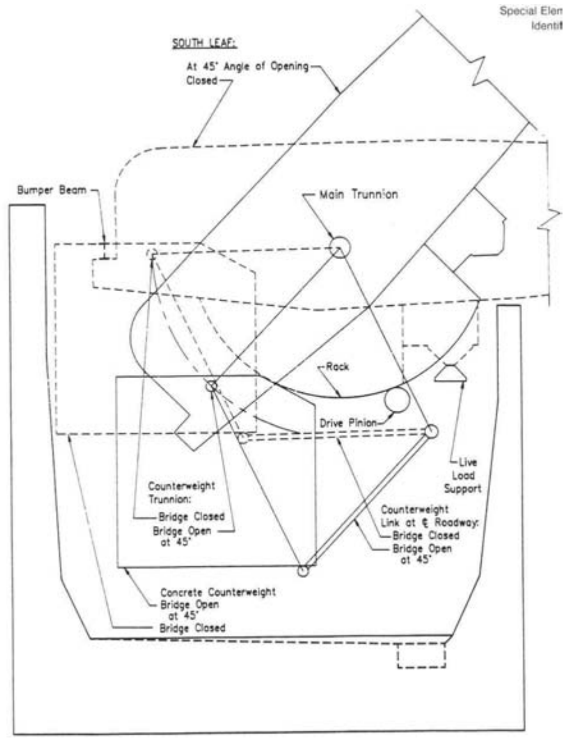


Figure 12.2.14 Multi-Trunnion, Strauss Type Bascule Bridge, in which the Counterweight Link Keeps the Counterweight Hanging Vertically from the Counterweight Trunnions while the Moving Leaf Rotates about the Main Trunnions

12.2.4 Vertical Lift Bridges Design Characteristics

Vertical lift movable bridges have a movable span with a fixed tower at each end. The span is supported by steel wire ropes at its four corners. The ropes pass over sheaves (pulleys) atop the towers and connect to counterweights on the other side. The counterweights descend as the span ascends (see Figure 12.2.15).

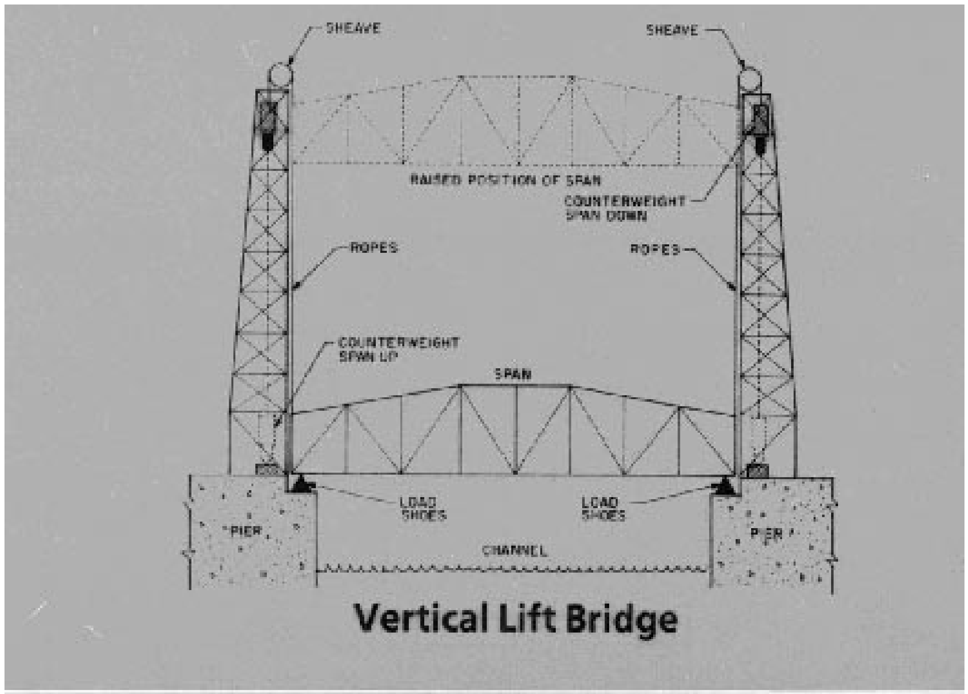


Figure 12.2.15 Vertical Lift Bridge Schematic

There are two basic types of vertical lift bridges:

- Power and drive system on lift span
- Power and drive system on towers

Power and Drive System on Lift Span

The first vertical lift bridge completed during 1894 in Chicago was designed by J.A.L. Waddell. This type locates the power on top of the lift truss span. The actual lifting is accomplished using "up-haul and down-haul ropes" where turning drums wind the up-haul (lifting) ropes as they simultaneously unwind the down-haul ropes (see Figures 12.2.16). A variation of this type provides drive pinions at both ends of the lift span which engage racks on the towers.

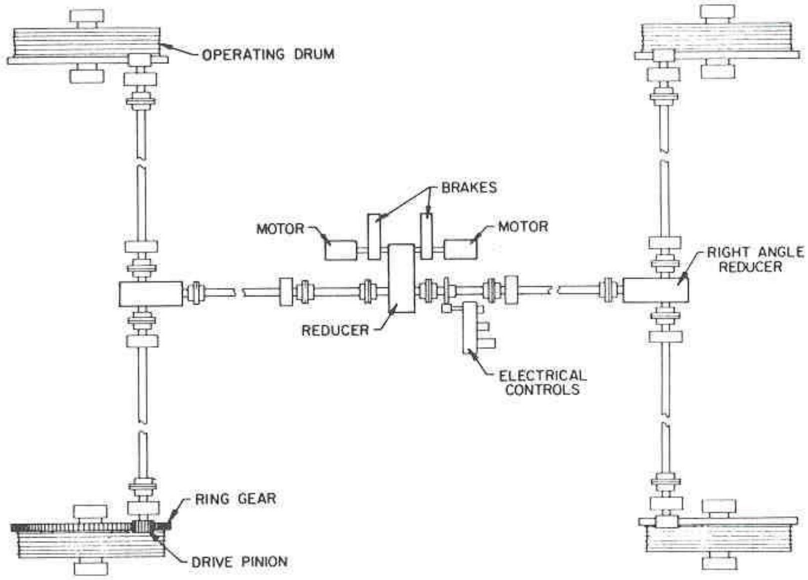


Figure 12.2.16 Vertical Lift Bridge Machinery is Located on Top of the Lift Truss Span, and the Operating Drums Rotate to Wind the Up-Haul (Lifting) Ropes as They Simultaneously Unwind the Down-Haul Ropes

Power and Drive System on Towers

The other basic type of vertical lift bridge locates the power on top of both towers, where drive pinions operate against circular racks on the sheaves. The lifting speed at both towers must be synchronized to keep the span horizontal as it is lifted (see Figures 12.2.17 and 12.2.18).

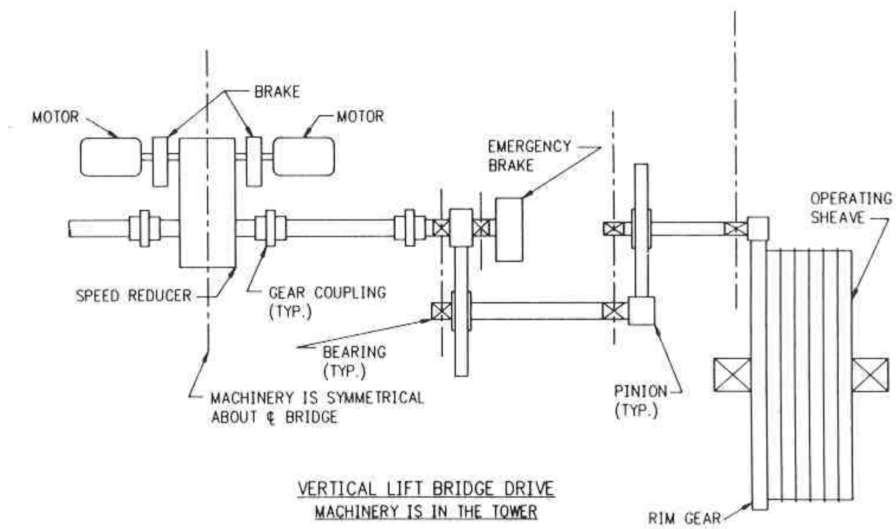


Figure 12.2.17 Vertical Lift Bridge Machinery is Located on the Towers, and the Rim Gears (and Operating Sheaves) are Rotated to Raise and Lower the Bridge

Figure 12.2.18 Vertical Lift Bridge with Power and Drive System on Towers

12.2.5 Special Elements Common to All Movable Bridges

Particular attention should be given to the special elements found in swing bridges, bascule bridges, and vertical lift bridges during inspection. These elements are commonly found on all types of movable bridges.

Open Gearing

Open gearing is used to transmit power from one shaft to another and to alter the speed and torque output of the machinery. Beveled gears are also used to change direction (see Figure 12.2.19).

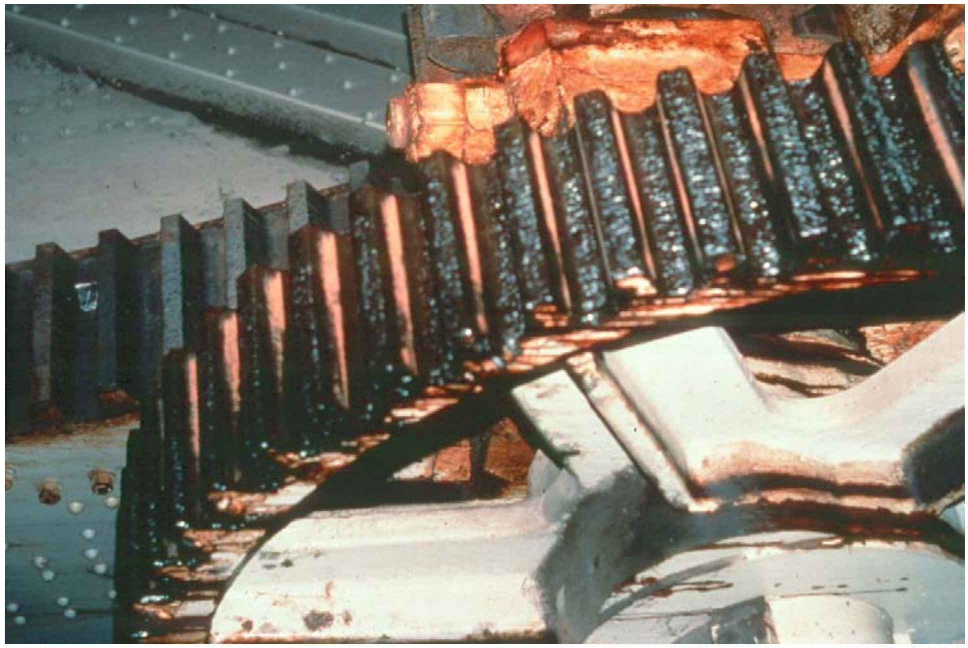


Figure 12.2.19 Open Gearing

Speed Reducers Including Differentials

Speed reducers including differentials serve the same function as open gearing (see Figure 12.2.20). However, they may contain several gear sets, bearings, and shafts to provide a compact packaged unit, which protects its own mechanical elements and lubrication system with an enclosed housing. Differential speed reducers also function to equalize torque and speed from one side of the mechanical operating system to the other.

Figure 12.2.20 Speed Reducer

Shafts and Couplings

Shafts transmit mechanical power from one part of the machinery system to another. Couplings transmit power between the ends of shafts in line with one another, and several types can be used to compensate for slight imperfections in alignment between the shafts (see Figure 12.2.21).

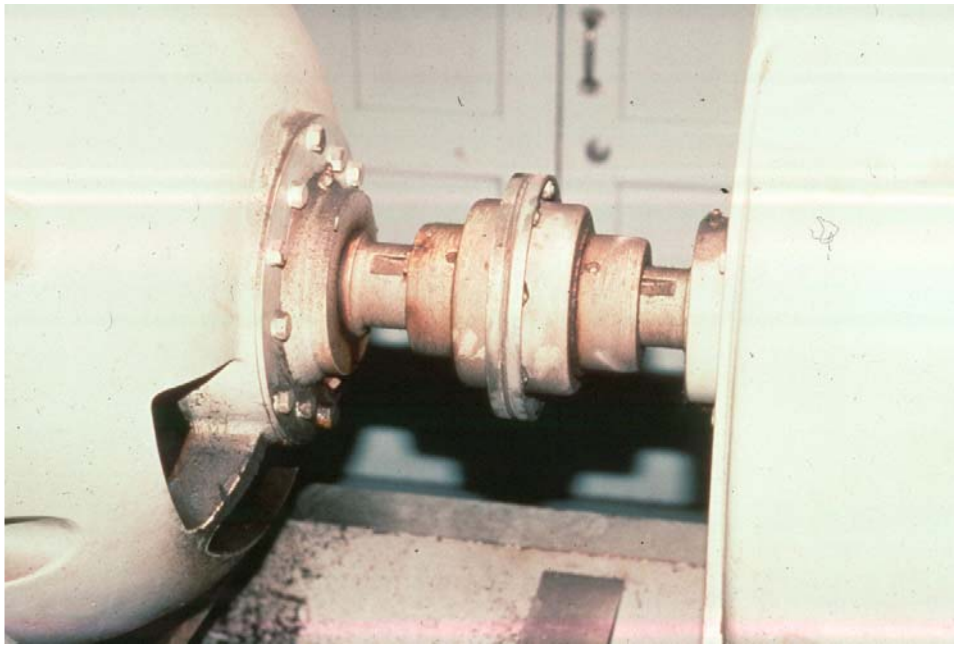


Figure 12.2.21 Coupling

Bearings

Bearings provide support and prevent misalignment of rotating shafts, trunnions, and pins (see Figure 12.2.22).

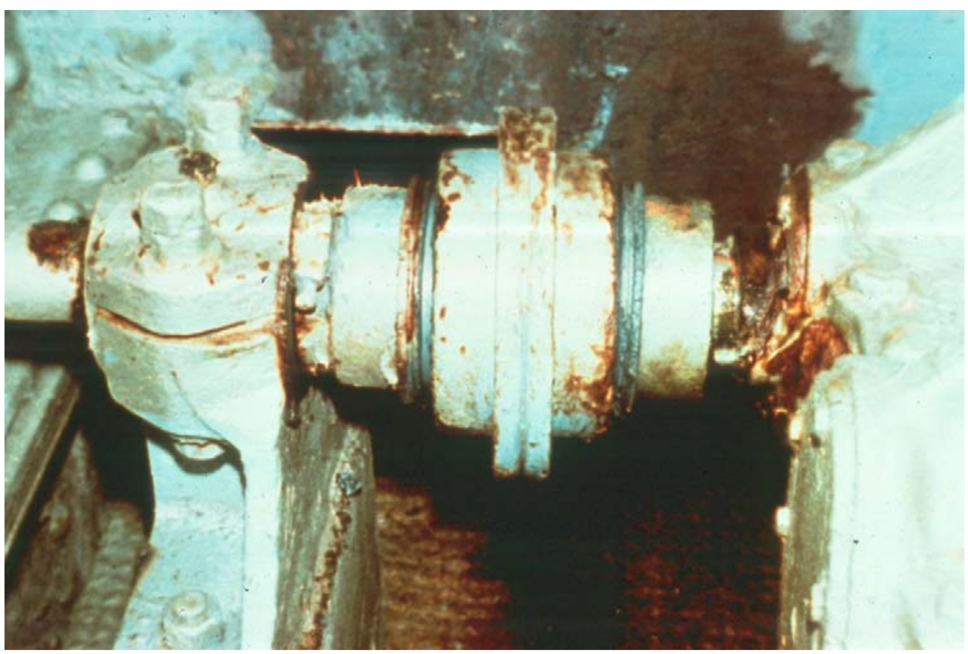


Figure 12.2.22 Bearing

Brakes

Brakes can be of either the shoe type or disc type, and can be released manually, electrically, or hydraulically (see Figure 12.2.23 and 12.2.24). They are generally spring applied for fail safe operation. Motor brakes are located close to the drive to provide dynamic braking capacity, except that some types of drives can provide their own braking capability, thereby eliminating the need for separate motor brakes. Machinery brakes are located closer to the operating interface between movable and fixed parts of the bridge and are used to hold the span statically, in addition to serving as emergency brakes in many cases. Supplemental emergency brakes are sometimes also provided.

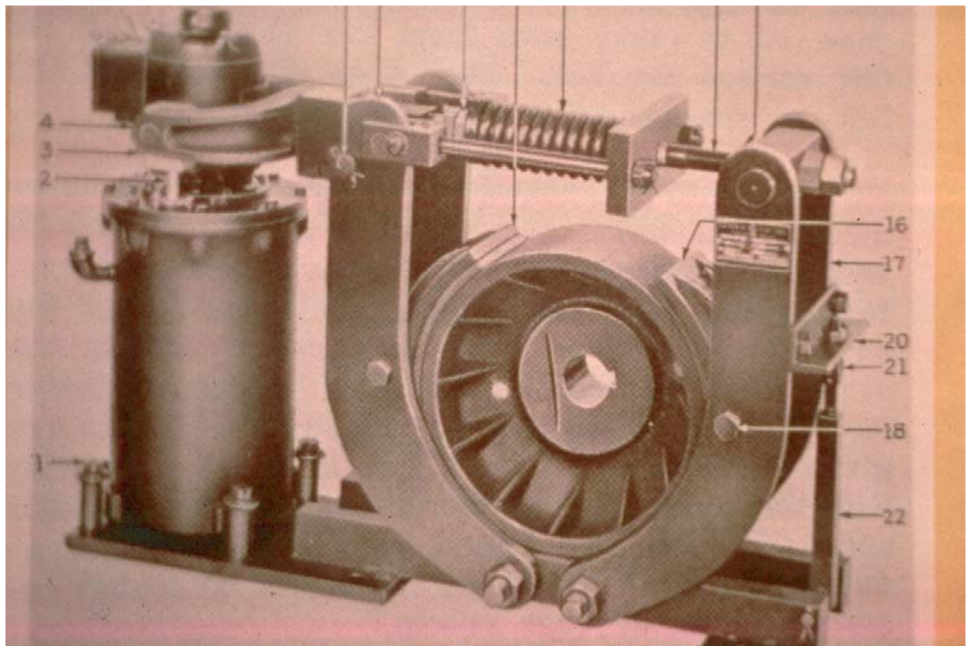


Figure 12.2.23 Shoe Type Break

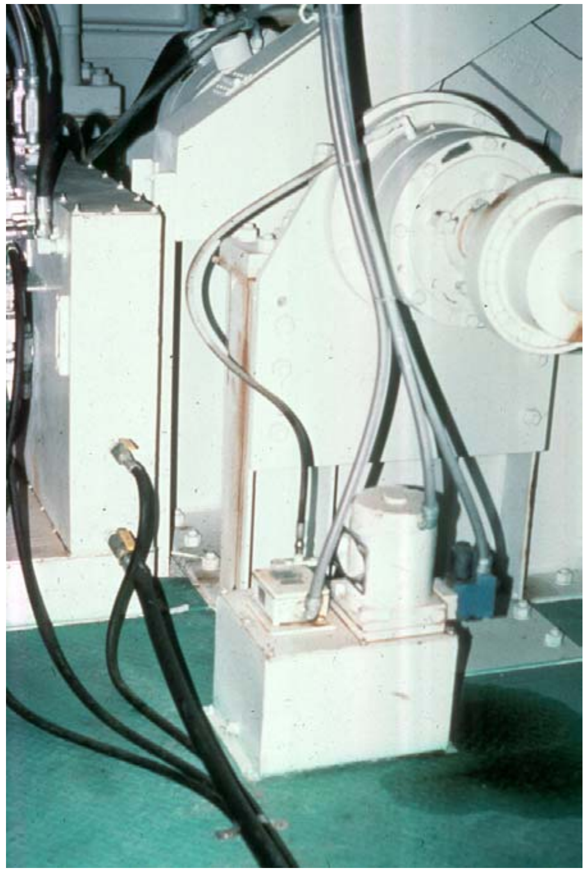


Figure 12.2.24 Spring Set Hydraulically Released Disc Break

Drives

Drives can consist of electric motors, hydraulic equipment, or auxiliary drives.

- Electric Motors - For electric motors, either AC or DC power may be used. AC power is often used to power wound rotor motors with torque controllers on older bridges, while new bridges may utilize squirrel cage induction motors with adjustable frequency speed control. DC motors can also provide speed control.

- Hydraulic Equipment - For hydraulic equipment, prime movers may include either large actuating cylinders or hydraulic motors (see Figure 12.2.25). Either type of drive must be supplied with pressure to provide force and fluid flow to provide speed to the operating system. Electrically operated hydraulic power units consisting of a reservoir and pump, with controls, provide power to the operating systems.

- Auxiliary Drives - For auxiliary drives, emergency generators are provided to serve in the event of power failure. Auxiliary motors and hand operators, with their clutches and other mechanical power transmission components, are provided to serve in the event the main drive fails (see Figure 12.2.26). In some cases, to prevent the need for larger auxiliary generators, the auxiliary motors are required for use any time the auxiliary generators are used, requiring increased time of operation.

Figure 12.2.25 Low Speed High Torque Hydraulic Motor

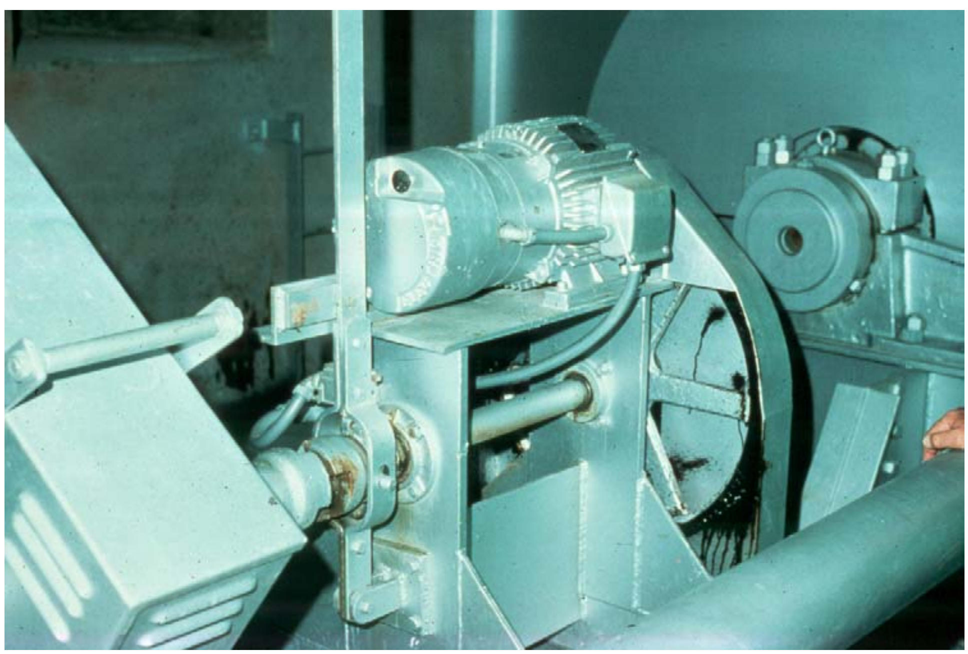


Figure 12.2.26 AC Emergency Motor

Air Buffers and Shock Absorbers

Air buffers and shock absorbers are located between the span and the pier at points where impact may occur between the two (see Figures 12.2.27 and 12.2.28). A cross section of the buffer shows the air chamber and seals on the piston. As the span lowers, the rod is pushed in, causing the air inside to be compressed (see Figure 12.2.29). A pressure relief valve allows the air to escape beyond the pressure setting. Force is required to build-up and keep the pressure of the air at the movement of the span for a “soft” touchdown on the bearings. Shock absorbers provide the same purpose as the air buffers. However, they are completely self-contained and, therefore, require very little maintenance.

Figure 12.2.27 Air Buffer

Figure 12.2.28 Shock Absorber

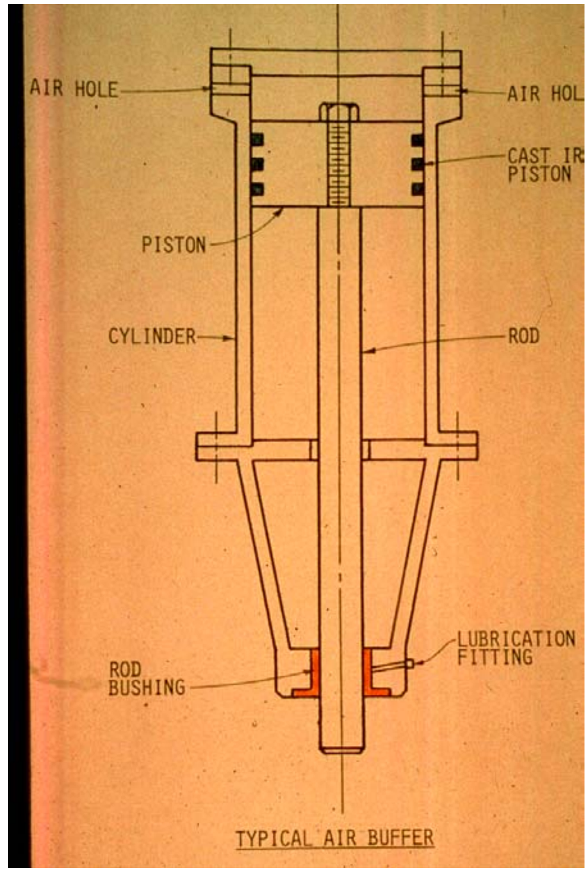


Figure 12.2.29 Typical Air Buffer Schematic

Span Locks

Span lock bars at the end of the span are driven when the span is fully closed to prevent movement under live load. Span locks may also be provided at other locations on the span to hold the span in an open position against strong winds or to prevent movement from an intermediate position. They can be driven either mechanically or hydraulically (see Figure 12.2.30 and 12.2.31).

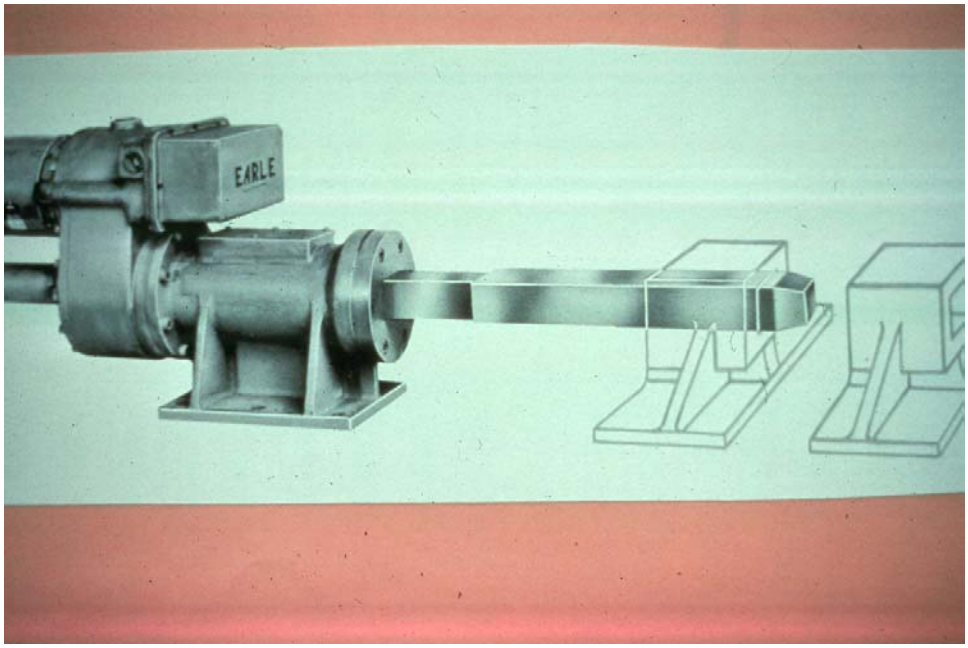


Figure 12.2.30 Typical Mechanically Operated Span Lock

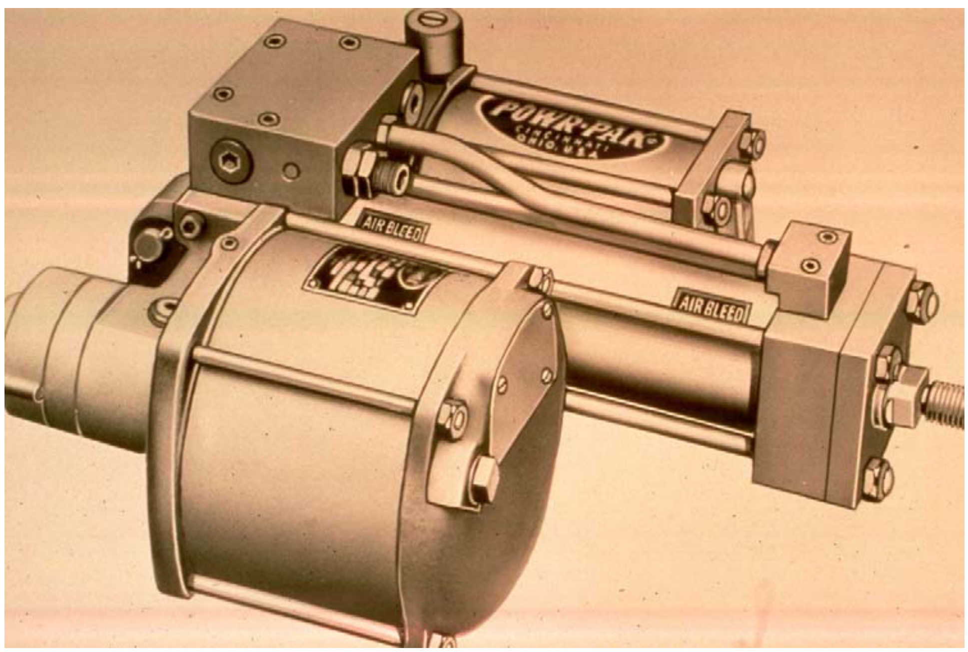


Figure 12.2.31 Hydraulic Cylinder that Drives Lock Bars

Counterweights

Adjustable quantities of counterweight blocks are provided in addition to the permanent counterweight, which is part of the structure so that adjustments may be made from time to time due to changes in conditions (see Figure 12.2.32 and 12.2.33). A movable span is designed to function in a balanced condition, and serious unbalanced conditions will cause overstress or even failure of the mechanical or structural elements.

Figure 12.2.32 Concrete Counterweight on a Single-Leaf Bascule Bridge

Figure 12.2.33 Concrete Counterweight on a Vertical Lift Bridge

Live Load Shoes and Strike Plates

Live load shoes and strike plates between the movable and fixed portions of the bridge are designed to bear most or all of the live load when the bridge is carrying traffic (see Figure 12.2.34).

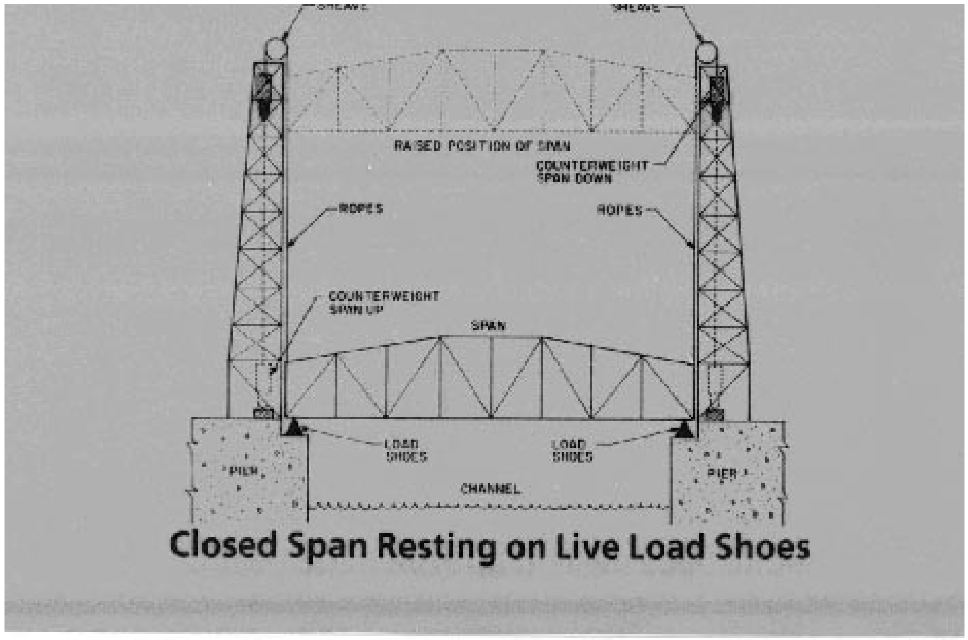


Figure 12.2.34 Closed Span Resting on Live Load Shoes

Traffic Barriers

Traffic barriers are heavyduty movable gates or posts that are designed to prevent a vehicle from plunging from the roadway into the draw or into the pit below the bridge (see Figure 12.2.35. Their operation is important for public safety. They are used mainly in situations where a large opening exists between the approach span and the movable span when it is open.

Figure 12.2.35 Traffic Barrier

12.2.6 Swing Bridge Special Elements

Swing bridges are designed utilizing the following special elements.

Pivot Bearings

In center-bearing types (with balance wheels), the axially loaded thrust bearing is usually composed of spherical discs, attached to top and bottom bases, enclosed in an oil box to provide lubrication and prevent contamination (see Figure 12.2.36). In rim-bearing types, the pivot bearing is also enclosed but will be radial loaded, maintaining the position of the pivot shaft or king pin.

Figure 12.2.36 Center Pivot Bearing

Balance Wheels

On center-bearing types only, non-tapered balance wheels bear on the circular rail concentric to the pivot bearing only when the span is subjected to unbalanced loading conditions (see Figure 12.2.37). At other times, when the span is not subjected to unbalanced loads, a gap should be found between each wheel and the rail.

Figure 12.2.37 Balance Wheel in-place over Circular Rack

Rim-Bearing Rollers

Usually tapered to allow for the differential rolling distance between the inside and outside circumferences of the rail circle, rim-bearing rollers should bear at all times.

Wedges

End wedges are used to raise the ends of the span and support live load under traffic (see Figure 12.2.38). The end wedge bearings are under all four corners of the span. Center wedges are used to stabilize the center of the span and to prevent the center bearing from supporting live load. Wedges may be actuated by machinery and linkage, which connects wedges to actuate together, or each wedge may have its own actuator (see Figure 12.2.39).

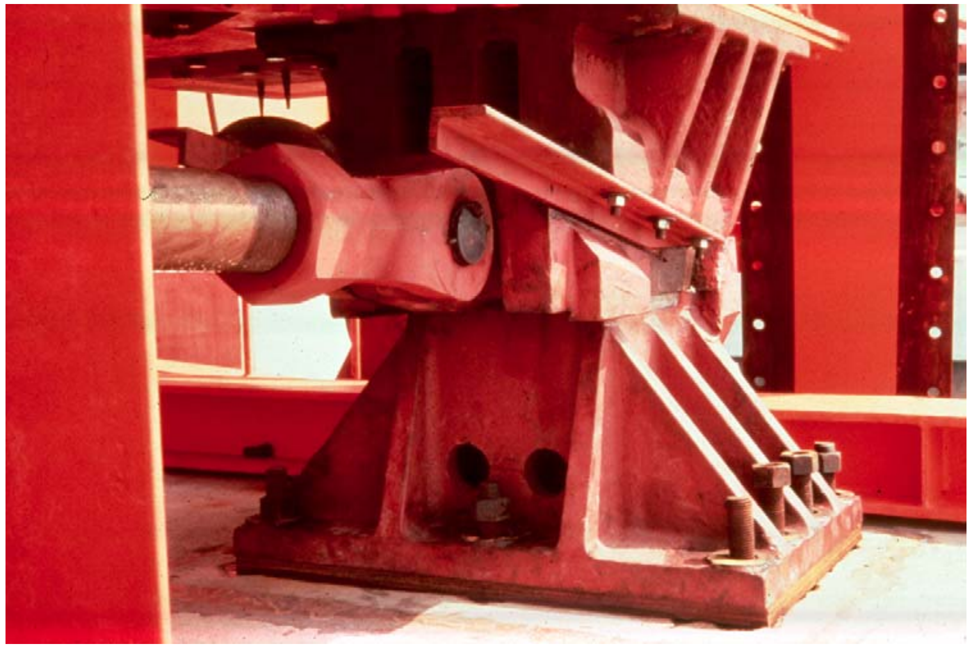


Figure 12.2.38 End Wedge

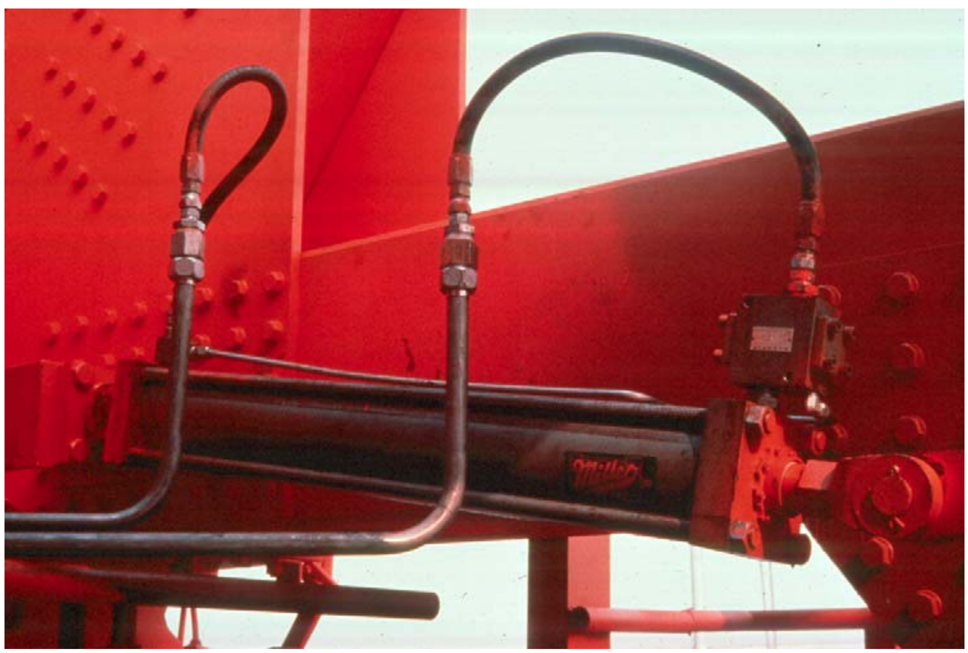


Figure 12.2.39 Hydraulic Cylinder Actuator

End Latches

Located at the center of one or both rest piers, end latches generally consist of a guided tongue with roller mounted on the movable span that occupies a pocket mounted on the rest pier when the span is in the closed position. To open the span, the tongue is lifted until it clears the pocket at the time the wedges are withdrawn (see Figure 12.2.40). As the span is swung open, the latch tongue is allowed to lower or fall into a position in which the roller may follow along a rail or track mounted on the pier. When closing, the tongue rolls along the rail or track and up a ramp which leads to the end latch pocket where the tongue is allowed to drop to center the span.

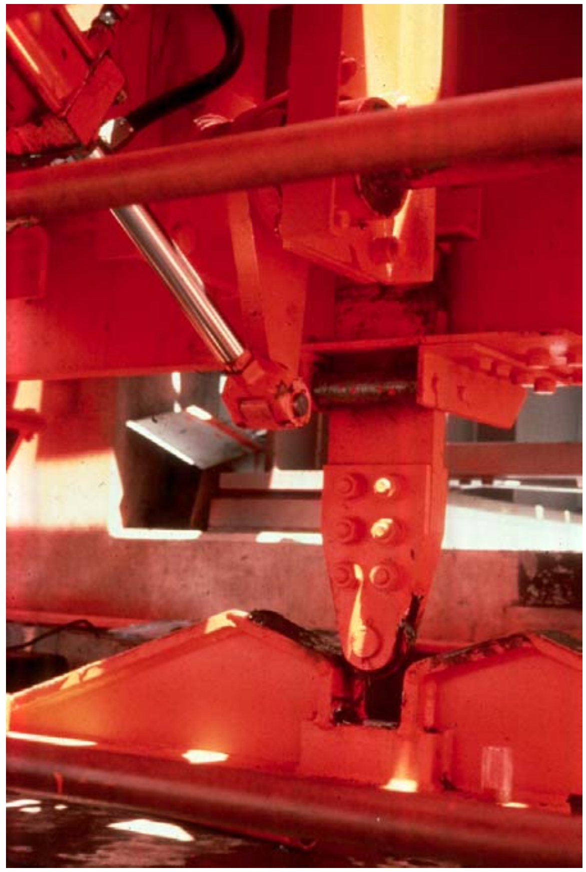


Figure 12.2.40 End Wedges Withdrawn and End Latch Lifted so the Roller on the Bottom can Roll up the Slope on the Inside

12.2.7 Bascule Bridge Special Elements

Bascule bridges utilize the following elements peculiar to their design.

Rolling Lift Tread and Track Castings

Rolling lift tread and track castings are rolling surfaces which support the bascule leaves as they roll open or closed (see Figure 12.2.41). Tread sockets and track teeth prevent transverse and lateral movement of the span due to unbalanced conditions, such as wind, during operation and especially when held in the open position.

Figure 12.2.41 Circular Lift Tread and Track Castings

Racks and Pinions

- Rolling lift rack and pinion - The driving pinion engages the rack teeth at the centerline of the roll (see Figure 12.2.42).

- Trunnion rack and pinion - The circular rack casting are attached in the plane of the truss (or girder) in front of the counterweight (see Figures 12.2.43 and 12.2.44).

The drive pinions are overhung in order to engage the rack teeth. A cover is placed over the pinions for safety and to keep debris from falling on it.

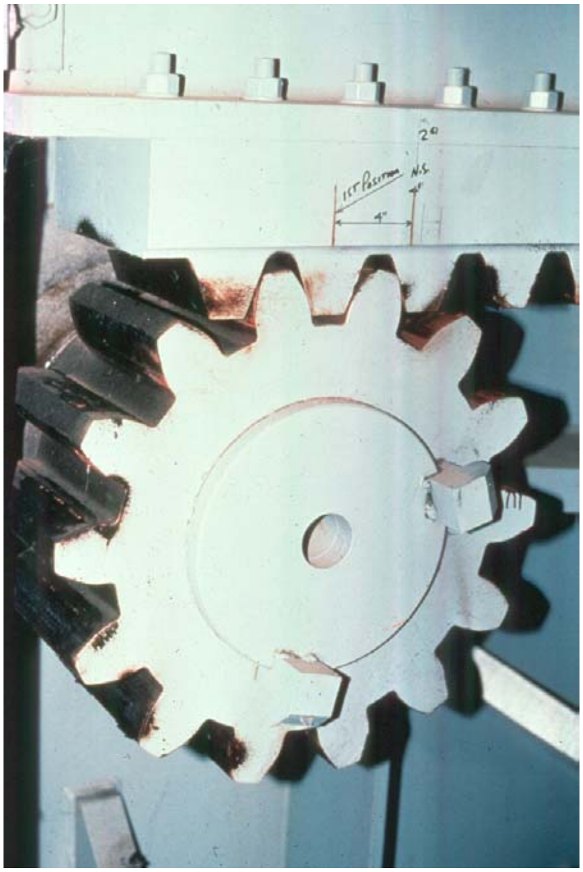


Figure 12.2.42 Rack Casting and Pinion

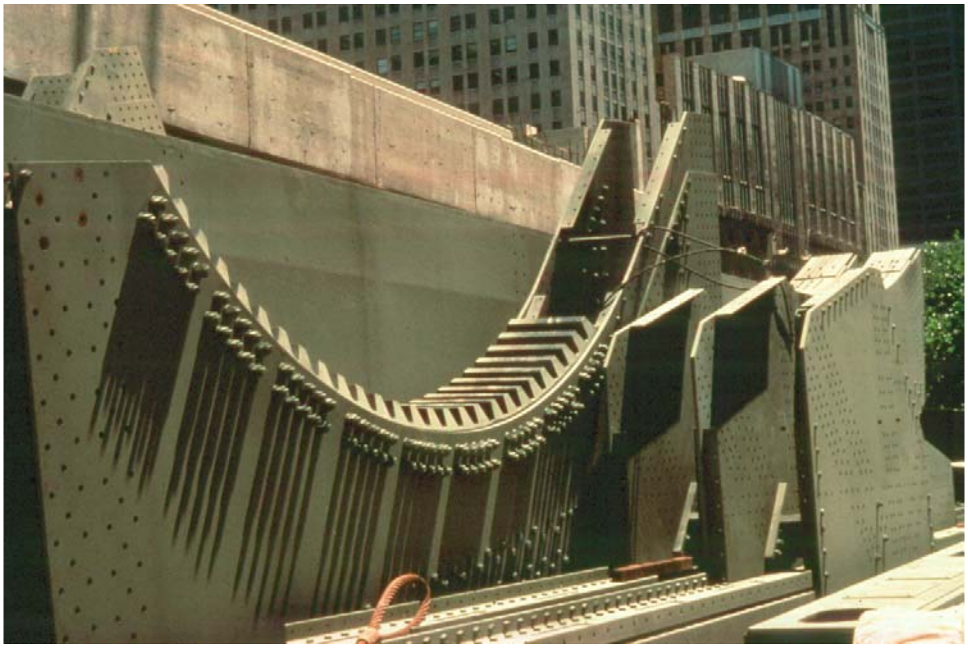


Figure 12.2.43 Rack Casting Ready for Fabrication

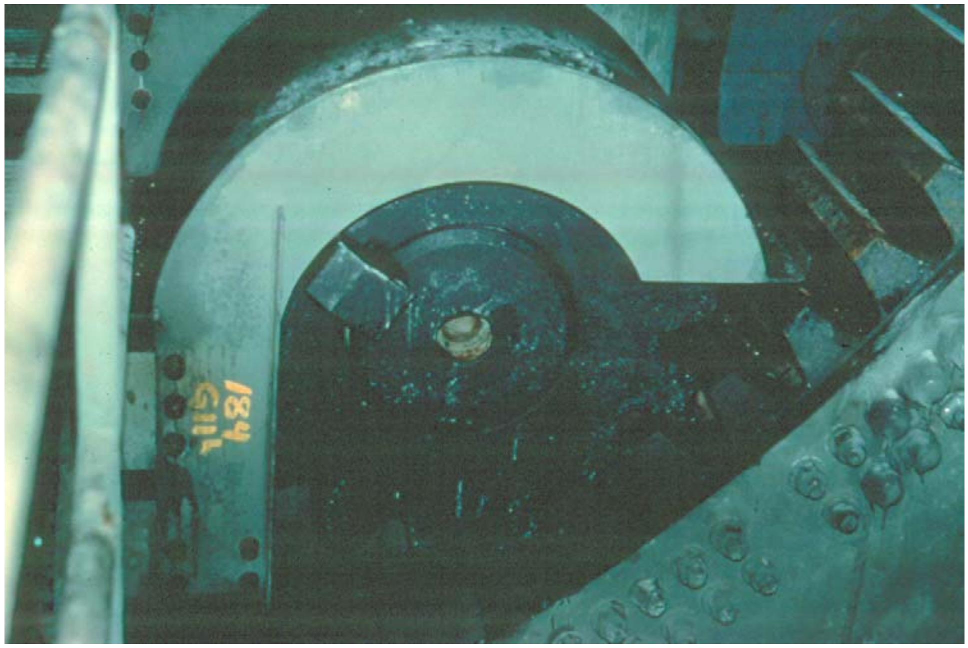


Figure 12.2.44 Drive Pinion

Trunnions and Trunnion Bearings

Trunnions and trunnion bearings (see Figure 12.2.45), which are large pivot pins or shafts and their bearings, entirely support the leaf as it rotates during operation as well as supporting dead load when the bridge is closed. Some designs, which do not provide separate live load supports, also require the trunnions to carry live load (see Figure 12.2.46).

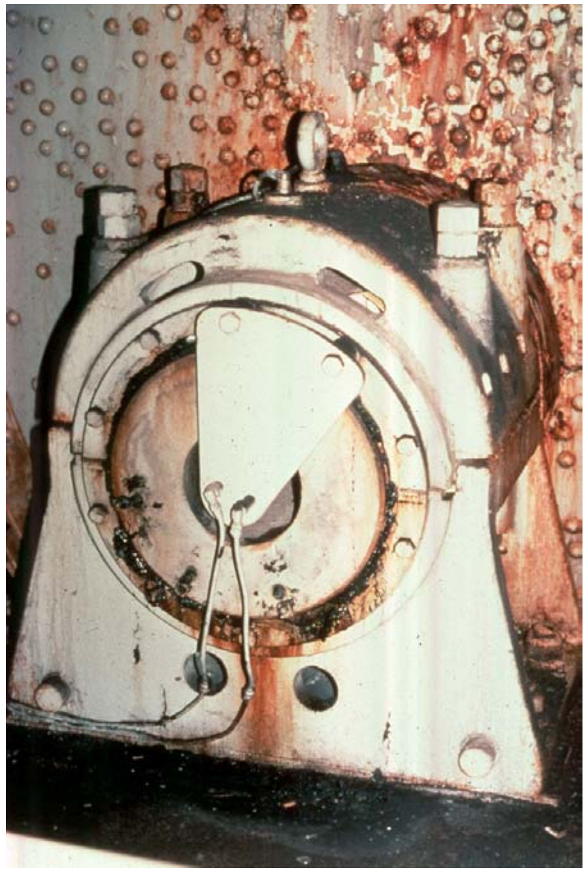


Figure 12.2.45 Trunnion Bearing

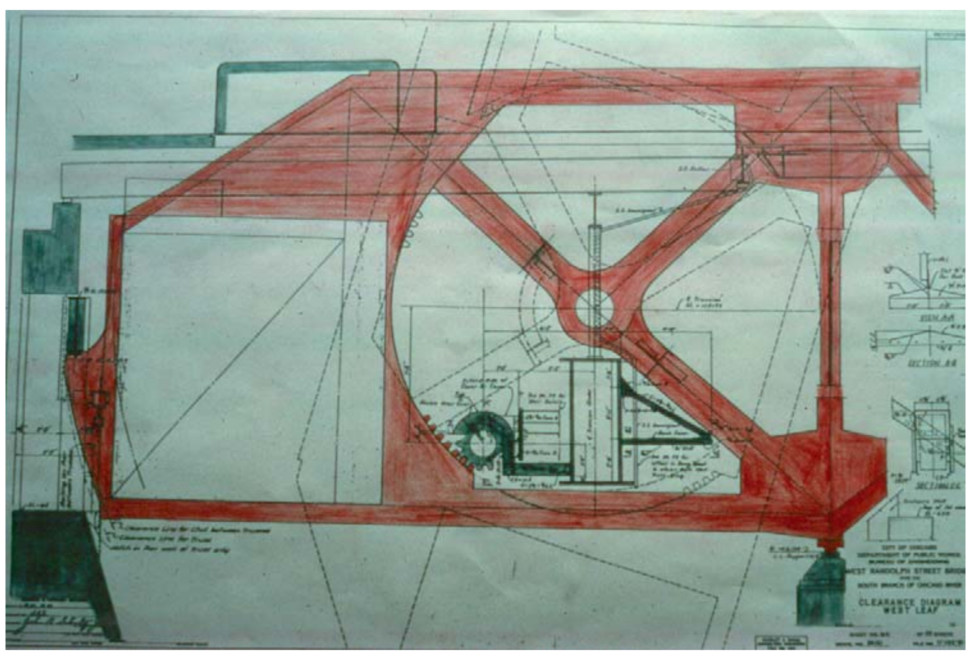


Figure 12.2.46 Trunnion Design Drawing

Hopkins Frame

A Hopkins frame machinery arrangement is provided on some trunnion bascule bridges. The main drive pinion locations are established in relationship to their circular racks by a pivot point on the pier and pinned links attached to the trunnions.

Tail (Rear) Locks

Located at the rear of the bascule girder on the pier, tail locks prevent inadvertent opening of the span under traffic or under a counterweight-heavy condition should the brakes fail or be released (see Figure 12.2.47).

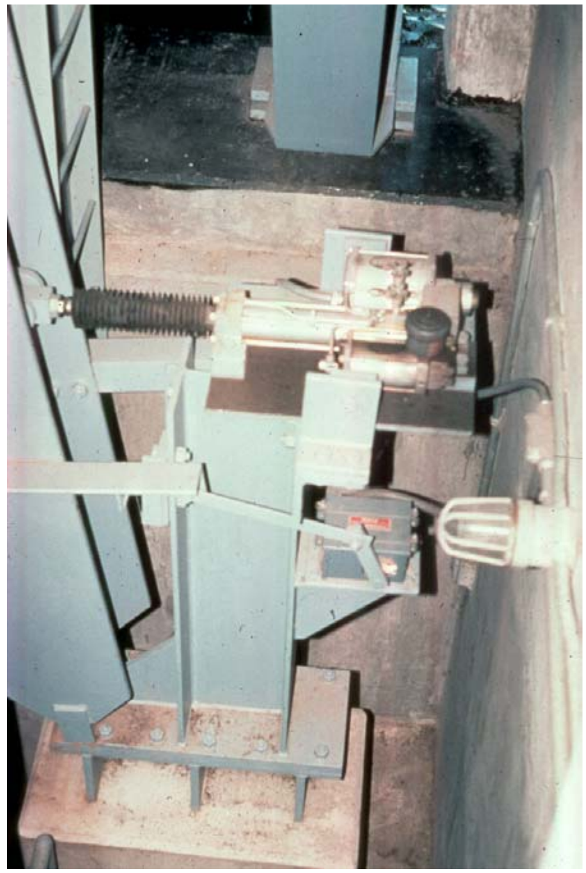


Figure 12.2.47 Rear Lock Assembly

Center Locks

Center locks are provided to transfer shear load from one leaf to the other when the bridge is under traffic. Center locks may consist of a driven bar or jaw from one leaf engaging a socket on the other leaf, or may be a meshing fixed jaw and diaphragm arrangement with no moving parts (see Figure 12.2.48). Without the center lock engaged, a double-leaf bascule functions as a cantilevered span, experiencing four times the bending moment, with proportional increases in stresses, at the pier.

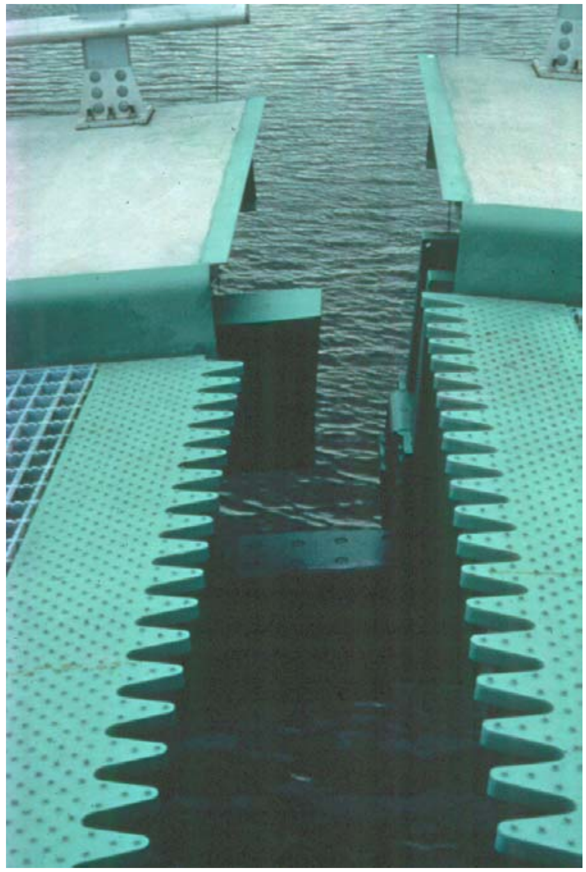


Figure 12.2.48 Center Lock Jaws

Transverse Locks

In twin bascule bridges that are split longitudinally to allow flexibility during construction, repair, or rehabilitation, transverse locks between the inside girders are used to keep the pairs together during operation (see Figure 12.2.49). These are usually operated manually, as they are not normally used for long periods of time.

Figure 12.2.49 Transverse Locks on Underside can be Disengaged

12.2.8 Vertical Lift Bridge Special Elements

Vertical lift bridges may utilize the following elements peculiar to their design.

Wire Ropes and Sockets

Wire ropes and sockets include up-haul and down-haul operating ropes and counterweight ropes (see Figure 12.2.50 and 12.2.51). Ropes consist of individual wires twisted into several strands that are wound about a steel core. Fittings secure the ends of the rope and allow adjustments to be made.

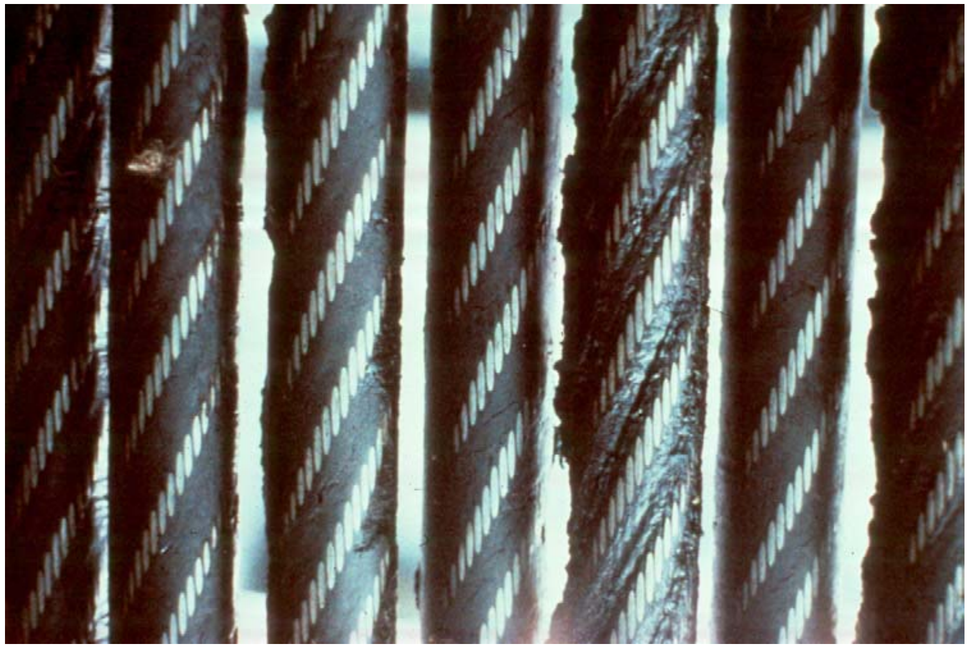


Figure 12.2.50 Wire Rope

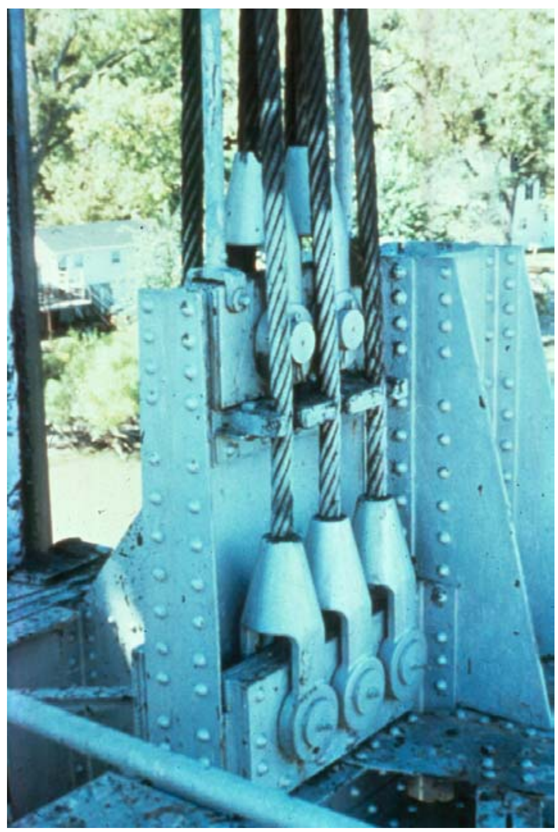


Figure 12.2.51 Wire Rope Sockets and Fittings

Drums, Pulleys, and Sheaves

Drums are used to wind a rope several times around to extend or retract it (see Figure 12.2.52). Pulleys and sheaves change the direction of the rope or guide it at intermediate points between ends of the rope.

Figure 12.2.52 Drums Wind Up the Up-Haul (Lifting) Ropes as they Simultaneously Unwind the Down-Haul Ropes

Span and Counterweight Guides

Span and counterweight guides are located between tower and span or counterweight to prevent misalignment.

Balance Chains

Balance chains are provided to compensate for the weight of counterweight rope that travels from the span side to the counterweight side of the sheaves at the top of the tower as the span is raised. Weight of chain is removed from the counterweight and is supported by the tower as rope weight is increased on the counterweight side of the sheaves on the tower.

Span Leveling Devices

Whether mechanical or electrical, span leveling devices compensate and adjust the movement of the two ends of the span during operation to prevent unsynchronized movement.

12.2.9 Overview of Common Defects

Steel

Common defects that can occur to steel members of movable bridges include:

- Failure of the Paint System
- Pitting
- Surface Rust

- Section Loss
- Fatigue Cracking
- Collision Damage
- Overload Damage
- Heat Damage

Refer to Topic 2.3 for a more detailed presentation of the properties of steel, types and causes of steel deterioration, and the examination of steel.

Concrete

Common defects that occur to concrete members of movable bridges include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Stress corrosion

Refer to Topic 2.2 for a more detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

12.2.10 Inspection Locations and Procedures - Safety

Movable Bridge Inspector Safety

It is imperative that all movable bridge inspectors coordinate their work with the Bridge Operator and emphasize the need for advance warning of a bridge opening. The Bridge Operator should not operate the bridge until being notified by all inspectors that they are ready for an opening. There are many ways that this can be accomplished, such as placing a warning note on the control console or opening the circuit breakers and locking the compartment to the equipment that they will be inspecting.

Inspection Considerations

Important considerations for a movable bridge inspector include observing and making comments in the inspection report on the following.

Public Safety

Public safety considerations include:

- Good visibility of roadway and sidewalk for Bridge Operator (see Figure 12.2.53).
- Adequate time delay on traffic signals for driver reaction.
- Adequate time delay before lowering gates.
- Interlock - all "gates down" before raising bridge (bypass available if traffic signals are on).
- Interlock - bridge must be closed before gates can be raised (bypass

available if locks are driven).

- Interlock - traffic signals do not turn off until all gates are fully raised (bypass available).
- Observe the location of the bridge opening in relation to the gates, traffic lights and bells, and determine whether approaching motorists can easily see them. Check their operation and physical condition to determine if they are functioning and well maintained. Recommend replacement when conditions warrant it.
- Unprotected approaches, such as both ends of a swing bridge and vertical lift bridge and the open end of a single-leaf bascule bridge, should preferably have positive resistance barriers across the roadway, with flashing red lights as provided on the gate arms (see Figure 12.2.54).
- High-speed roadways and curved approaches to a movable bridge should preferably have advanced warning lights (flashing yellow).

Figure 12.2.53 Operator's House with Clear View of Traffic Signals and Lane Gates

Figure 12.2.54 Traffic Control Gate

Navigational Safety

Navigational safety considerations include:

- Minimum underclearance designated on the permit drawing should be provided. Compliance with minimum channel width with any restriction on vertical clearance when span is open for navigation.
- All navigation lights should have a relay for backup light, and red span lights should not change to green until both leaves are fully open (see Figure 12.2.55).
- Marine radio communication (depends on the need) (see Figure 12.2.56).
- Operator should be able to automatically sound the emergency signal to navigation vessels if bridge cannot be opened.
- Navigation lights are very important and should be checked for broken lenses, deteriorated insulation of wiring and cable, and dry and clean interior.
- Underclearance gauges for closed bridges must be inspected for accuracy, visibility, and legibility.

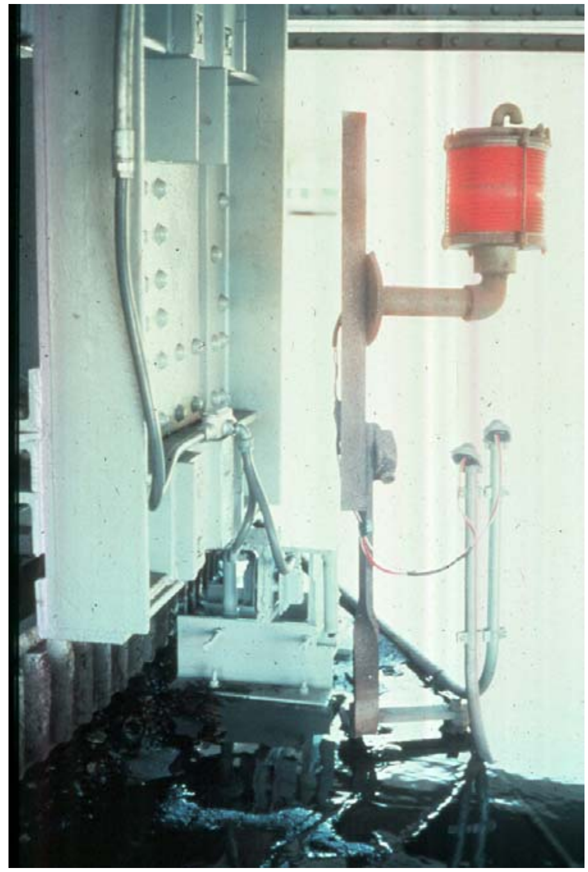


Figure 12.2.55 Navigational Light

Figure 12.2.56 Marine Two-Way Radio Console

Structure Safety

Structure safety considerations include:

- Structural ability to carry the anticipated loads.
- Presence of pressure relief valves on hydraulic power units to limit hydraulic forces applied to machinery and structure.
- Keeping horsepower applied to machinery and structure within design limits by limiting speed.

Dependable Operation

The movable bridge should be operated in the normal and emergency modes to check all interrelated interlocks and to be sure every component is operational.

12.2.11 Inspection Locations and Procedures of Movable Bridge Opening and Closing Sequences

Interlocking for Normal Operation

During normal operation, the inspector should verify that each interlock functions properly and can be bypassed (when provided). The controls for the traffic signals, traffic gates, center or rear locks, emergency brakes, and the bridge operation should be so interlocked that they can only be operated in the following sequences.

Opening Sequence

The bridge opening sequence should be as follows:

1. Activate traffic signals.
2. Lower oncoming gates and, when traffic has cleared, lower off-going gates. "All gates down" interlocked for withdrawing locks (bypass provided).
3. Press "raise" button if automatic operation is provided or, if manual operation is provided, proceed as follows:

   a. Withdraw locks - "Locks Withdrawn." Interlocked for bridge operation (no bypass).
   b. Release emergency brakes - no interlock provided. Warning buzzer sounds if brakes are not released when power is applied to motors to move bridge.
   c. Accelerate leaves to full speed.
   d. When advanced to nearly open position, decelerate leaves to slow speed and stop at nearly open position.
   e. At nearly open position, with reduced power, lower leaves to stop at fully open position.
   f. Set emergency brakes.

Closing Sequence

The bridge closing sequence should be as follows:

1. Press "lower" button if automatic operation is provided or, if manual operation is provided, proceed as follows:

a. Release emergency brakes.
b. Accelerate leaves to full speed.
c. For all types of bridges with lock bars:

(1) At advanced nearly closed position, decelerate leaves to slow speed. Leaves should stop at nearly closed position by action of the bridge limit switch.
(2) At nearly closed position with reduced power, lower leaves to stop at fully closed position.
(3) With machinery wound up (bascule bridges and counterweight heavy vertical lift bridges) or when span is fully closed (swing bridges and span heavy vertical lift bridges), set the brakes and drive lock bars.

d. For rolling lift bridges having jaw and diagram shear locks with no moving parts:

(1) At advanced nearly closed position, decelerate to slow speed. The jaw leaf should stop at the "locking position" (within the "window" to receive the diaphragms) by action of the bridge limit switch.
(2) At advance nearly closed position, decelerate to slow speed. The diaphragm leaf should stop in the "clear position" (where the lower jaw will clear the diaphragm) by action of the bridge limit switch.
(3) Foot switch must be depressed to provide reduced power from this point until both leaves are closed.
(4) Lower the diaphragm leaf to make "soft" contact with lower jaw.
(5) Close both leaves together with diaphragm castings against lower jaws.
(6) When leaves are fully closed, drive the rear locks. "Fully closed" interlock provided for rear lock operation (no bypass).
(7) Set emergency brakes with reduced power applied to motors to hold machinery wound up.

2. Deactivate automatic traffic control, or manually raise gates:

a. All gates raise, off-going gates should start up before oncoming gates raise.
b. Warning signals and red lights should not turn off until all gates are raised, even if the power switch is turned "off" (bypass should be provided), after which the green traffic lights are turned "on."

Bypass Note: All bypass switches should have handles that are spring returned to "off." When the switch is turned to bypass momentarily, a holding relay should hold the bypass activated until power is removed from the controls or the switch is turned to cancel bypass. These circuits should be provided in order to prevent inadvertent use of any bypass. Until a malfunction is corrected, the operator must therefore initiate the use of any bypass switch that is needed every time the bridge is operated.

12.2.12 Inspection Locations and Procedures for the Control House

The operator is responsible for public and navigational safety during operation and, together with maintenance personnel, should be most familiar with any known structural or operational defects. Operational and maintenance log books should be kept in the control house for reference. The resources within the control house can therefore provide a great deal of general information, through the knowledge of its personnel and the records stored there. The position of the control house should provide the best general view of the bridge itself.

Inspection of the control house should include:

- Consult with the bridge operators to ascertain whether there are any changes from the normal operation of the bridge.
- Note where the control panel is located in relation to roadway and waterway, and also whether the bridge operator has a good view of approaching boats, vehicles, and pedestrians (see Figure 12.2.57). Check operation of all closed circuit TV equipment, and evaluate its position for safe operation.
- Note whether the structure shows cracks, and determine whether it is windproof and insulated.
- If controls are in more than one location, note description of the other locations and include their condition as well as the information about the control house.
- Note whether all Coast Guard, Corps of Engineers, and local instructional bulletins are posted.
- Note whether alternate warning devices such as bullhorns, lanterns, flasher lights, or flags are available.
- Check for obvious hazardous operating conditions involving the safety of the operator and maintenance personnel.
- Check for any accumulations of debris, which may be readily combustible.
- Check controllers while bridge is opening and closing. Look for excess play and for sparking during operation.
- Note whether the submarine cables are kinked, hooked, or deteriorated, especially at the exposed area above or below the water. In tidal areas, check for marine and plant growth. Note if the ends of the cable have been protected from moisture.

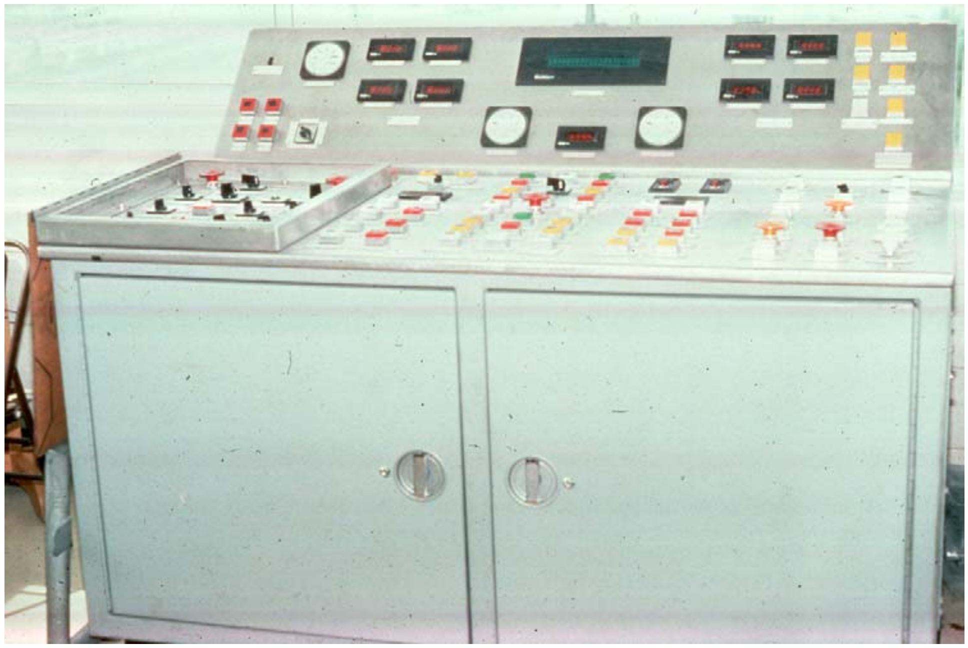


Figure 12.2.57 Control Panel

12.2.13 Inspection Locations and Procedures for Structural Members

Defects, Damage, and Deterioration

Defects, damage, and deterioration, typically detrimental to all steel and concrete structures, must be noted during the inspection of all types of movable bridges. Most of the bridge structure defects and deterioration listed elsewhere as potential problems apply to movable spans also.

Fatigue

Fatigue can be a problem with movable bridges due to the reversal or the fluctuation of stresses as the spans open and close (see Figure 12.2.58). Any member or connection subject to such stress variations should be carefully inspected for fatigue failure.

Figure 12.2.58 Normal Operations can Cause Stress Reversals in Members, Leading to Fatigue

Counterweights and Attachments

Inspection of counterweights and attachments should include:

- Inspect the counterweights to determine if they are sound and are properly affixed to the structure. Also check temporary supports for the counterweights that are to be used during bridge repair and determine their availability should such an occasion arise.

- Where steel members pass through or are embedded in the concrete check for any corrosion of the steel member and for rust stains on the concrete.

- Look for cracks and spalls in the concrete.

- Check for debris, birds, animals, and insect nests in the counterweight pockets.

- Where lift span counterweight ropes are balanced by chains (or other means), make sure the links hang freely, and check these devices along with slides, housings, and storage devices for deterioration and for adequacy of lubrication, where applicable (see Figure 12.2.59).

- Determine whether the bridge is balanced and whether extra balance blocks are available. A variation in the power demands on the motor, according to the span's position, is an indication of an unbalanced leaf or span. If the controls provide a "drift" position, it should be used to test the balance.

- Paint must be periodically removed from a lift span properly; otherwise, the counterweights will eventually be inadequate.

- Determine whether the counterweight pockets are properly drained. On vertical lift bridges, be sure that the sheaves and their supports are well drained. Examine every portion of the bridge where water can collect. All pockets that are exposed to rain and snow should have a removable cover.

Figure 12.2.59 Counterweights on Vertical Lift Bridge

Piers

Inspection of piers on movable bridges should include:

- Check the pier protection system (see Figure 12.2.60).
- Take notice of any rocking of the piers when the leaf is lifted. This is an indicator of a serious deficiency and should be reported at once.
- Check the braces, bearings, and all housings for cracks, especially where stress risers would tend to occur.
- Inspect the concrete for cracks in areas where machinery bearing plates or braces are attached (see Figure 12.2.61). Note the tightness of bolts and the tightness of other fastening devices used.
- Survey the spans including towers to check both horizontal and vertical displacements. This will help to identify any foundation movements that have occurred.

Figure 12.2.60 Pier Protection Systems – Dolphins and Fenders

Figure 12.2.61 Concrete Bearing Areas

Steel Grid Decks

Structural welds should be sound and the grid decks should have adequate skid resistance. Check the roadway surface for evenness of grade and for adequate clearance at the joints where the movable span meets the fixed span. For more information on steel grid decks, see Topic 5.3.

Concrete Decks

A solid concrete roadway is used over the pier areas (pivot or bascule pier) to keep water and debris from falling through onto the piers. Since the machinery room is usually under the concrete deck, check the ceiling for leaks or areas that allow debris and rust to fall on the machinery. For more information of concrete decks, see section 5.2.

Other Structural Considerations

Other structural considerations include:

- On swing bridges, check the wedges and the outer bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of span or uplift when load comes upon the other span.

- Examine the live load bearings and wedges located under the trusses or girders at the pivot pier for proper fit alignment and amount of lift.

- On double-leafed bascule bridges, measure the differential vertical movement at the joint between the two leaves under heavy loads. On other types, check for this type of movement at deck joints (breaks in floor) between movable and fixed portions of the structure. This can indicate excessive wear on lock bars or shear lock members.

- Inspect the joint between the two leaves on double-leaf bascule bridges, or the joints between fixed and movable portions of the structure for adequate longitudinal clearance for change in temperature (thermal expansion).

- On bascule bridges, see if the front live load bearings fit snugly. Also observe the fit of tail locks at rear arm and of supports at outer end of single-leaf bridges.

- Inspect the fully open bumper blocks and the attaching bolts for cracks in the concrete bases.

- Examine the counterweight pit for water. Check the condition of the sump pump, the concrete for cracks, and the entire area for debris.

- See if the shear locks are worn. Measure the exterior dimensions of the lock bars or diaphragm casting and the interior dimensions of sockets or space between jaws to determine the amount of clearance (wear). Excessive movement should be reported and investigated further.

- On rolling lift bascule bridges, check the segmental and track castings and their respective supporting track girders (if used) for wear on sides of track teeth due to movement of sockets on segmental castings. Compare all wear patterns for indications of movement of the leaves. Check for cracking at the fillet of the angles forming the flanges of the segmental and track girders, cracking in the flanges opposite joints in the castings, and cracking of the concrete under the track. Inspect rack support for lateral movement when bridge is in motion.

- On multi-trunnion (Strauss) bascule bridges, check the strut connecting the counterweight trunnion to the counterweight for fatigue cracks. On several bridges, cracking has been noted in the web and lower flanges near the gusset connection at the end nearer the counterweights. The crack would be most noticeable when the span is opened.

12.2.14 Inspection Locations and Procedures for Machinery Members

Mechanical, electrical, and hydraulic equipment includes specialized areas, which are beyond the scope of this manual. Since operating equipment is the heart of the movable bridge, it is recommended that expert assistance be obtained when conducting an inspection of movable spans. It should be noted that in many cases, the owners of these movable bridges follow excellent programs of inspection, maintenance, and repair. However, there is always the possibility that some important feature may have been overlooked.

Trial Openings

Conduct trial openings as necessary to insure proper operational functioning and that the movable span is properly balanced. Trial openings should be specifically for inspection. During the trial openings, the safety of the inspection personnel should be kept in mind.

Machinery Inspection Considerations

On all movable structures, the machinery is so important that considerable time should be devoted to its inspection. The items covered and termed as machinery include all motors, brakes, gears, tracks, shafts, couplings, bearings, locks, linkages, over-speed controls, and any other integral part that transmits the necessary mechanical power to operate the movable portion of the bridge. Machinery should be inspected not only for its current condition, but operational and maintenance procedures and characteristics of operation should also be analyzed. The items listed below and items similar to them should be inspected and analyzed by a machinery or movable bridge specialist. Refer to FHWA-IP-77-10, Bridge Inspector's Manual for Movable Bridges and the AASHTO Movable Bridge Inspection, Evaluation and Maintenance Manual, for further information on inspecting these items. The FHWA-IP-77-10 manual is published by the Federal Highway Administration (FHWA), but is currently out of print.

Operation and General System Condition

Observe the general condition of the machinery as a whole, and its performance during operation. Check for smoothness of operation, and note any abnormal performance of components. Noise and vibration should also be noted, and the source determined. Unsafe or detrimental procedures followed by the operator should be noted to prevent injury to the public or to personnel, or damage to the equipment. The condition of the paint system should also be noted.

Maintenance Procedures

An evaluation of maintenance procedures in light of design details for the equipment should be done. Application methods and frequency of lubrication should be checked in the maintenance logbook, if available. General appearance of existing applied lubricant should be noted.

Mechanical Elements

The following are condensed guidelines for various mechanical elements.

Open Gearing

Check open gearing for tooth condition and alignment including over- and under-engagement. The pitch lines should match. Excessive or abnormal wear should be noted. Inspect the teeth, spokes, and hub for cracks. Observe and note the general appearance of the applied lubricants on open gearing. If the lubricant has been contaminated, especially with sand or other gritty material, it should be removed and new lubricant applied. If there is a way to prevent future contamination, it should be recommended in the inspector's comments in the report. Check the teeth of all gears for wear, cleanliness, corrosion, and for proper alignment.

Speed Reducers Including Differentials

The exterior of the housing and mountings should be examined for cracks and damage (see Figure 12.2.62 and 12.2.63). Check bolts for tightness and note any corrosion. The interior of the housing should be inspected for condensation and corrosion. Check the condition of gears. Watch for abnormal shaft movement during operation, indicating bearing and seal wear. Oil levels and condition of lubricant should be checked periodically through the use of sampling and analysis techniques. Circulating pumps and lubricating lines should be observed for proper operation. Abnormal noise should be noted.

Figure 12.2.62 Cracked Speed Reducer Housing

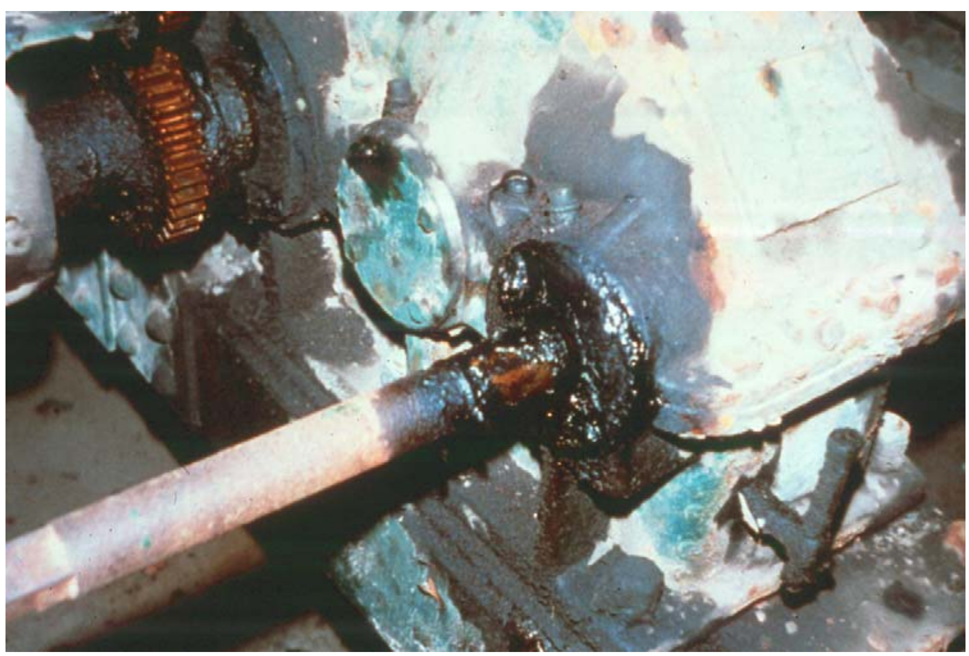


Figure 12.2.63 Leaking Speed Reducer

Shafts and Couplings

Shafts should be examined for damage, twisting, and strain. Cracks, if suspected, may be detected using dye penetrant (see Figure 12.2.64). Misalignment with other parts of the machinery system should be noted. Cracks in shafts should be measured and the exact location recorded. Consideration should be given to replacement of the shaft. Other shafts should be examined in the same locations as they were probably made from the same material and fabricated to the same details. They have also been exposed to the same magnitude and frequency of loading. Coupling hubs, housings, and bolts should be checked for condition. Seals and gaskets should be inspected for leaks. Internal inspection of couplings is warranted if problems are suspected and can be used to determine tooth wear in gear couplings.

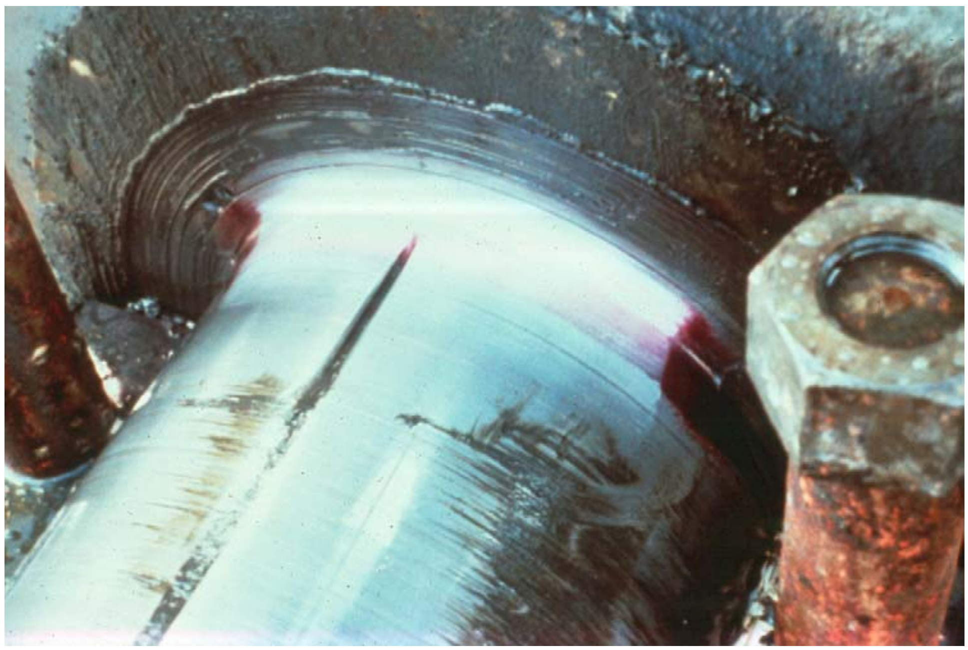


Figure 12.2.64 Hairline Crack Revealed on Shaft from Dye Penetrant Test

Bearings

Bearing housings, pedestals, and supports should be examined for external condition. Any cracks should be noted. Bolts in housings and those used for anchors should be checked for tightness, damage, and corrosion. Apparent lubrication characteristics should be noted. Grinding noises can be caused by dry bearings (unlubricated) (see Figure 12.2.65). In sleeve bearings, the bushings should be inspected for damage and excessive wear. Evidence of seal damage in anti-friction bearings should be noted. Unusual noise should be investigated. Check the trunnion bearings for excessive wear, lateral slip, and loose bolts.

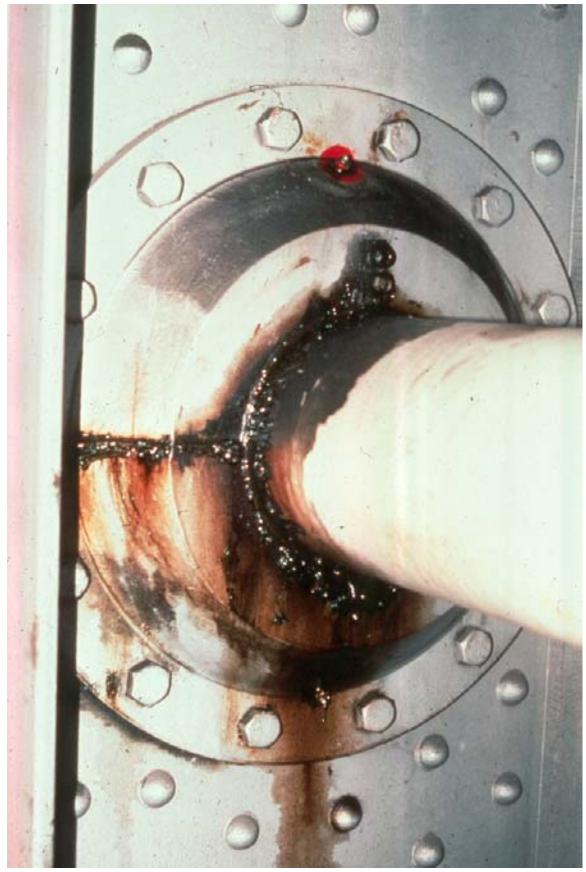


Figure 12.2.65 Dry Bearing

Brakes

Inspect all braking devices for proper setting of braking torque and for complete release of the brakes when actuated. On shoe brakes, check drums and shoes for wear, damage, and corrosion, for misalignment of shoes with drums, and for clearance when released. Determine if worn linings need replaced. Check for proper actuation without leakage by actuators. Linkages and hand releases should be free but not sloppy. On enclosed hydraulic disc brakes, make certain there is proper actuation without leakage at connections or seals. Check the brakes, limit switches, and stops (cylinders and others) for excessive wear and slip movement. Note whether the cushion cylinder ram sticks or inserts too easily. The brake limit switches should be inspected for proper setting. Observe the surface of the brake drum for indications of contact with the brake shoes. Check the pressure developed by each disc brake power unit to be sure the brakes are releasing. Also check the manual release on all of the brakes.

Drives - Electric Motors

Check the housing and mountings for damage, corrosion, and fastener condition. Inspect bearings for lubrication and note indications of wear (movement) and seal leakage at shaft extensions.

Drives - Hydraulic Equipment

Look for any leakage at connections and seals. Note any corrosion on the cylinder rods. Listen to motors and pumps, and note any unusual noise. Power units should be checked to make sure all components are functioning and that pressures are properly adjusted. Fluid should be sampled periodically and examined for contamination and wear metal. Check all main hydraulic power units for charge pressure setting and maximum pressure that can be developed by the unit. All filters must be checked routinely and replaced as needed. The level of fluid in the vertical reservoir should also by checked.

Auxiliary Drives

Check emergency generators for operation and readiness. There should be no oil leaks or abnormal noises. Mechanical service specialists and electrical inspectors are required for more thorough inspections. Auxiliary motors and hand operators, with their clutches and other transmission components, should be checked for adjustment and readiness to perform when called upon.

Drives - Internal Combustion Engines

The detailed inspection of internal combustion engines should be made by mechanical engine specialists. Inspection should also include but not be limited to the checking of the following conditions:

- If a belt drive is used, look for any wear or slippage. Note the condition of all belts and the need for replacement, if any.
- If a friction drive is used, all bracing and bearings should be tight.
- If a liquid coupling is used, make sure that the proper quantity of fluid is used. Look for leaks.

Locks

Examine the center locks and tail locks (if used) on double-leafed bascule spans, and the end locks on single-leaf bascule bridges, swing bridges, and vertical lift bridges. Note whether there is excessive deflection at these joints or vibration on the bridge. Inspect the locks for fit and for movement of the span or leaf (or leaves). Check lubrication and for loose bolts. The lock housing and its braces should have no noticeable movement or misalignment. The paint adjacent to the locks will have signs of paint loss or wear if there is movement. Check lock bars, movable posts, linkages, sockets, bushings, and supports for damage, cracks, wear, and corrosion.

Check all rear locks in the withdrawn position for clearance from the path of the moving leaf as it opens and for full engagement when the leaf is closed. The gap, if any, should be measured between the lock plate and the moving leaf bearing plate. Check each rear lock hydraulic drive unit for leakage of oil and operation for correct length of movement of the lock.

On bascule bridges, see if the front live load bearings fit snugly. Also observe the fit of tail locks at the rear arm and of supports at the outer end of single-leaf bridges.

Actuators should be examined for operational characteristics, including leakage if hydraulic. The quantity and quality of lubricant should be noted. Check for alignment, and analyze the type of wear that is occurring. Note condition of movable operators.

Live Load Shoes and Strike Plates

The fasteners and structure should be inspected for defects and corrosion. Contact surface conditions should be noted. Check for alignment and movement under load.

Air Buffer Cylinders and Shock Absorbers

Note indications of lack of pressure or stickiness during operation. Check piston rod alignment with strike plate. Note the condition of the rod and housing. There should be no hydraulic leakage. Check the air filter and function of any pressure reading or adjusting devices and the operating pressure, if possible. The air buffers should have freedom of movement and development of pressure when closing. Inspect the fully open bumper blocks and the attaching bolts for cracks in the concrete bases.

Machinery Frames, Supports, and Foundations

There should be no cracking in steel or concrete. Note corrosion and damage. Check for deflection and movement under load. The linkages and pin connections should have proper adjustment and functional condition. Check motor mounting brackets to ensure secure mounting.

Fasteners

Inspect the fasteners for corrosion, loss of section, and tightness.

Wedges

Check the wedges and the outer bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of span or uplift when load comes upon the other span.

Examine the live load bearings and wedges located under the trusses or girders at the pivot pier for proper fit alignment and amount of lift.

Special Machinery for Swing Bridges

Check center bearings for proper and adequate lubrication, oil leaks, and noise. Examine the housing for cracking, pitting, fit of joints, and note indications of span translation (irregular rotation) at racks and track. Measure for proper clearance of balance wheels above track. The tracks and balance wheels should be free of wear, pitting, and cracking. Check for proper and adequate lubrication at all lubrication points.

Balance characteristics should be noted as indicated by loads taken by balance wheels, and by drag on the rest pier rail.

Check the rim bearing for wear on tracks and rollers, particularly at rest positions where the bridge is carrying traffic. Examine the center pivots and guide rings for proper fit, and for wear, pitting, and cracking. Check for proper and adequate lubrication at all lubrication points.

The center (live load) wedges located under the trusses or girders at the pivot pier must be examined for proper fit (no lifting) and alignment. Check end wedges and bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of the span or uplift when live load crosses the other span. The end lift jacks, shoes, and all linkages must be inspected for wear, proper bearing under load, and proper adjustment.

Note the condition of end latches, including any modification that adversely affects their functional design.

Special Machinery for Bascule Bridges

On rolling lift bascule bridges, check the segmental and track castings and their respective supporting track girders (if used) for wear on the sides of track teeth due to movement of sockets on segmental castings. The trunnion assemblies must be inspected for deflection, buckling, lateral slip, and loose bolts. The trunnions themselves should have no corrosion, pitting, or cracking, particularly at stress risers. Check the balance of each leaf. Compare all wear patterns for indications of movement of the leaves. Check for cracking at the fillet of the angles forming the flanges of the segmental and track girders, cracking in the flanges opposite joints in the castings, and cracking of the concrete under the track. Inspect rack support for lateral movement when bridge is in motion.

Check trunnion bearings for lubrication of the full width of the bearing. Verify that extreme pressure (EP) lubrication oil of the proper grade is used.

Special Machinery for Vertical Lift Bridges

The condition of wire ropes and sockets, including wire rope lubrication, is important. Look for flattening or fraying of the strands and deterioration between them. This is reason for replacement. Similarly, check the up-haul and down-haul ropes to see if they are winding and unwinding properly on the drums. The need for any tension adjustments in up-haul and down-haul ropes should be noted. Determine whether ropes have freedom of movement and are running properly in sheave grooves. Look for any obstructions to prevent movement of the ropes through the pulley system, and check the supports on span drive type bridges. Check rope guides for alignment, proper fit, free movement, wear, and structural integrity of the longitudinal and transverse grooved guide castings. The grooved guide castings must be inspected closely for wear in the grooves. The cable hold-downs, turnbuckles, cleats, guides, clamps, splay castings, and the travel rollers and their guides must be examined.

Check for damage, including cracking, at drums and sheaves. Note the condition and alignment of span guides.

Check that balance chains hang freely, that span leveling devices are functioning, and that span and counterweight balance closely. Observe if span becomes "out of level" during lifting operation. Inspect spring tension, brackets, braces, and connectors of power cable reels.

12.2.15 Electrical Inspection Considerations

An electrical specialist should be available for the inspection of the electrical equipment. The inspection should be made using FHWA-IP-77-10, *Bridge Inspector's Manual for Movable Bridges* (FHWA-IP-77-10 is currently out of print). AASHTO Movable Bridge Inspection, Evaluation and Maintenance Manual, may aid in the movable bridge inspection. The inspector should observe the functional operation of the bridge and look for abnormal performance of the equipment. Check the operational procedures and safety features provided. Evaluate the maintenance procedures being followed and check the frequency of services performed.

Power Supplies

The normal power supply, standby power supply, and standby generator set (for emergency operation of bridge and service lighting) should be examined and the following noted:

- Take megger readings on the cable insulation values, noting the weather conditions, namely temperature and humidity.
- Make sure all cable connections are properly tightened.
- Measure the voltage and the current to the motors at regular intervals during the operation of the bridge.
- Check the collector rings and windings on the generator set.
- Test starting circuitry for automatic starting and manual starting.
- See if the unit is vibrating while running under load.

If the power cable has been repaired with a splice, note the condition of the splice box seal.

If no standby power supply has been provided, determine whether a portable generator could be used. A manual transfer switch would be a convenient way of connecting it.

Motors

Span drive motors, lock motors, brake thrustor motors, and brake solenoids should be examined for the same items as given for power supplies.

Transformers

Check dry transformer coil housings, terminals, and insulators, including their temperature under load. Observe the frames and supports for rigidity to prevent vibration. The liquid filled transformer should be checked in the same way, and the oil level should be checked while looking for leakage. Examine oil insulation test records.

Circuit Breakers

Check circuit breakers (e.g., air, molded case, and oil) and fuses, including the arc chute, contact surfaces, overload trip settings, insulation, and terminal connections. Examine oil insulation test records, and observe the closing and tripping operation. Record all fuse types and sizes being used.

Wires and Cables

Examine the wiring and cables for both power and control. Note whether the submarine cables are kinked, hooked, or deteriorated, especially at the exposed area above and below the water. In tidal areas, look for marine and plant growth. Note if the ends of the cable have been protected from moisture. Record the insulation value of each wire as measured by megger. Look for cracking, overheating, and deterioration of the insulation. Check for wear against surfaces and especially sharp edges. Check the adequacy of supports and that dirt and debris do not accumulate against the conduit and supports. Terminal connections, clamps, and securing clips should be checked for tightness, corrosion, and that there are wire numbers on the end of each wire. The weight of the wires or cables must be carried by the clamps and not by the wire connections at the terminal strips.

Cabinets

Examine the programmable logic controller (PLC) cabinets, control consoles and stations, switchboards (see Figure 12.2.66), relay cabinets, motor control centers (MCC), and all enclosures for deterioration, debris inside, drainage, operations of heater to prevent condensation, and their ability to protect the equipment inside. Check the operation of all traffic signals, traffic gates, traffic barriers, and navigation lights. Verify that the bridge is open to provide the clearance shown on the permit drawing before the green span light turns on. Check the traffic warning equipment and control circuits, including the advanced warning signals (if used), traffic lights/signals, gates, barriers, and the public address and communication equipment.

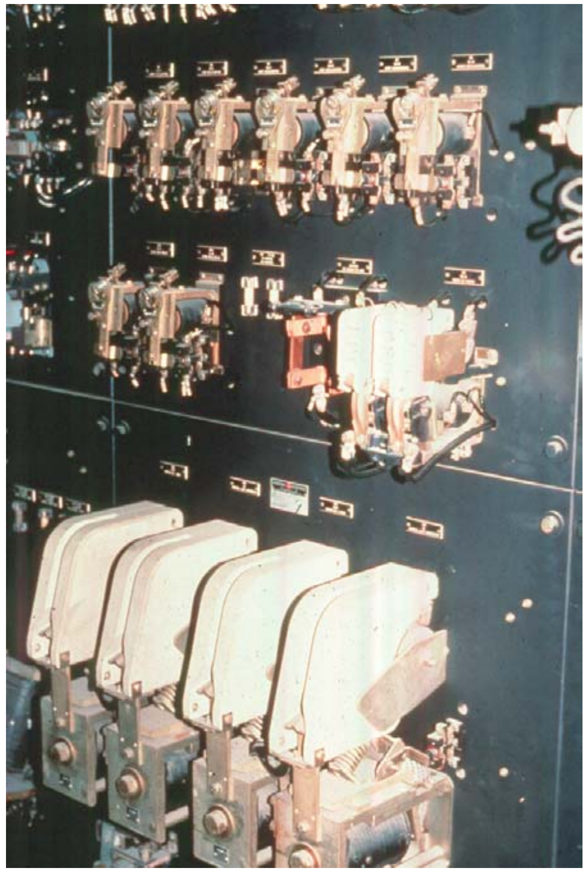


Figure 12.2.66 Open Switchboard

Conduit

See if all conduit is far enough away from all surfaces to avoid debris from collecting against it. Note if it is adequately supported and pitched to drain away from junction boxes and pull boxes, so that water is not trapped within. Also, note if all conduits have covers with seals. Report deteriorated conduit so that it can be replaced with new conduit. The connectors at the ends of all PVC coated conduit must be sealed and re-coated after all fittings are installed.

Junction Boxes

The covers on all junction boxes (JB's) should be examined for an effective seal, dry interior, functioning breather-drains, heaters having enough power to prevent condensation inside, and terminal strips all secured to the bottom of horizontal JB's or to the back of vertical JB's.

Meters

Observe if all voltmeters, ammeters, and watt meters are freely fluctuating with a change in load. All switches for meters should be operable.

Control Starters and Contactors/Relays

Check the operation of this equipment under load, and watch for arcing between contacts, snap action of contacts, deterioration of any surfaces, and drainage of any moisture. Look for signs of corrosion and overheating.

Limit Switches

All limit switches should be set so they do not operate until they are intended to stop the equipment or complete an interlock. The interior should be clean and dry, with all springs active.

Selsyn Transmitters and Receivers Check for power to the field and signal being sent from the transmitter to the receiver. Observe the receiver tracking the rotation of the bridge as it operates. Observe the mechanical coupling between the driving shaft and the transmitter, checking for damage and misalignment.

Service Light and Outlet Power should be going to each light and outlet. Note if there is a shield or bar for protecting each bulb and socket. It is desirable to have service lights available when power is removed from all movable bridge controls and equipment.

12.2.16 Hydraulic Inspection Considerations

A hydraulic power specialist should be available for the inspection of the hydraulic equipment (see Figure 12.2.67). The inspector should observe the functional operation of the bridge and look for abnormal performance of the equipment. Check the safety features provided and evaluate the maintenance procedures being followed, checking the frequency of services performed. Due to the inter-related function of components, the requirements for fluid cleanliness, and the need for personnel safety, the reservoir and hydraulic lines should not be opened. In addition, no components or parts of the power circuit should be shut off or adjusted without complete understanding of their function and knowledge of the effect such action will have upon the system. Items which should be checked during a hydraulic inspection include the following:

- Leakage anywhere in the system should be noted. Significant leakage should immediately be brought to the attention of the bridge authority.
- Check for corrosion of reservoir, piping, and connections.
- Sight gauges should be inspected for proper fluid level in reservoir. Note gauges with low fluid levels or gauges which cannot be read.
- Unusual noises from any part of the system should be noted.
- Check filter indicators to make sure filters are clean.
- A sample of the hydraulic fluid should be taken for analysis by a testing laboratory during periodic inspections.

Figure 12.2.67 Hydraulic Power Specialists

12.2.17 Recordkeeping and Documentation

General

The owner of a movable bridge must keep a complete file available for the engineer who is responsible for the operation and maintenance of the bridge. The file should include (if applicable), but not be limited to, the following:

- Copy of the latest approved permit drawing
- Complete set of design plans and special provisions
- "As-built" shop plans for the structural steel, architectural, mechanical, electrical, and hydraulic
- Machinery Maintenance Manual
- Electrical Maintenance Manual
- Hydraulic Maintenance Manual
- Copy of maintenance procedures being followed
- Copy of the latest Operator's Instruction being followed
- Copies of all inspection reports
- Copy of all maintenance reports
- Copy of all repair plans
- Up-to-date running log on all spare parts that are available, on order, or out of stock

Inspection and maintenance reports should be reviewed with preventative maintenance measures in mind. An example would be the "megger" readings on wiring insulation, especially those taken on damp rainy days when moisture could influence (reduce) the values. An acceptable minimum reading is usually 1 megohm. If the value on a wire is decreasing on progressive reports, preventative maintenance may save a "short" that could burn out equipment and put the bridge out of operation.

Inspection and Maintenance Data

Examples of inspection and maintenance records that should be kept are shown in Figures 12.2.68 through 12.2.74.

South Tower Differential Assembly GEARS - General 1.

Gear	General Condition	Lubrication	Keys	Alignment: Center Distance	Alignment: Axial	Alignment: Parallel
Pinion P5	Very Good. Tooth profiles show normal wear	Very Good	Good	Good. Pitch Lines Tangent	Good	Good
Gear I5	Very Good. Tooth profiles normal.	Very Good	Good	No Pitch Line on G5. Looks good. Measured backlash.		
Gear G5	Very Good. Tooth profiles normal	Very Good	Good			
Pinion P4	Very Good. Tooth profiles normal.	Very Good	Integral with shaft	No pitch line on P4. Center distance looks. Looks good. Measured backlash.	Good	Good
Gear G4	Very Good. Tooth profiles normal.	Very Good	Not keyed to shaft. Clutch locks G4 to shaft.			
Bevel Gears BG3 (2)	Very Good. Tooth profiles normal.	Very Good	Integral with sleeves.	Good. Pitch Lines 1/16" to 1/8" apart.	Good	Good
Bevel Pinions BP3 (2)	Very Good. Tooth profiles normal.	Very Good	Integral with shafts.			

Figure 12.2.68 Example of Notes on Operating Machinery (Gears-General)

South Tower Differential Assembly GEARS - Teeth 2.

Gear	Chordal Thickness		Backlash		Condition of Teeth					
								Abnormal		
	Original	Measured	Original	Measured	Normal	Pitting	Rolling-Peening	Scoring	Interference	Rust & Corr.
Pinion P5	.625"	Did not measure	.011" min to .020" max.	Did not measure. Pitch lines indicate good backlash.	✓					
Gear I5	.625"		.011" min		✓					
Gear G5	.625"		to .020" max.	.0135" Good.	✓					
Pinion P4	.625"		.011" min to	.020" Good	✓					
Gear G4	.625"		.020" max		✓					
Bevel Gears BG3 (2)	.875" at large end of teeth		.015" min to	Did not	✓					
Bevel Pinions BP3 (2)	.875" at large end of teeth		.029" max	measure. Pitch lines indicate good backlash.	✓					

Figure 12.2.69 Example of Notes on Operating Machinery (Gears-Teeth)

South Tower Differential Assembly BEARINGS 3

Bearing	General Condition	Clearance Original	Clearance Measured	Bolts	Lubri-cation
West end Emer. Motor Shaft	Good. Fairly clean, paint good. Bearing has 45° angle lube fitting w/dust cap.	.0025" min. to .0073" max.	.006" Good	Good. Nuts tight. Clean, paint good.	Good.
East end Emer. Motor Shaft		.0025" min. to .0073" max.	.006" Good		
West end Intermediate Shaft		.0025" min. to .0073" max.	.007" Good		
East end Intermediate Shaft		.0025" min. to .0073" max.	.005" Good		
West end Normal Motor Shaft		.0025" min. to .0073" max.	.007" Good		
East end Normal Motor Shaft		.0025" min to .0073" max	.009" Fair		

Figure 12.2.70 Example of Notes on Operating Machinery (Bearings)

South Tower Differential Assembly MECHANICAL COMPONENTS 4.

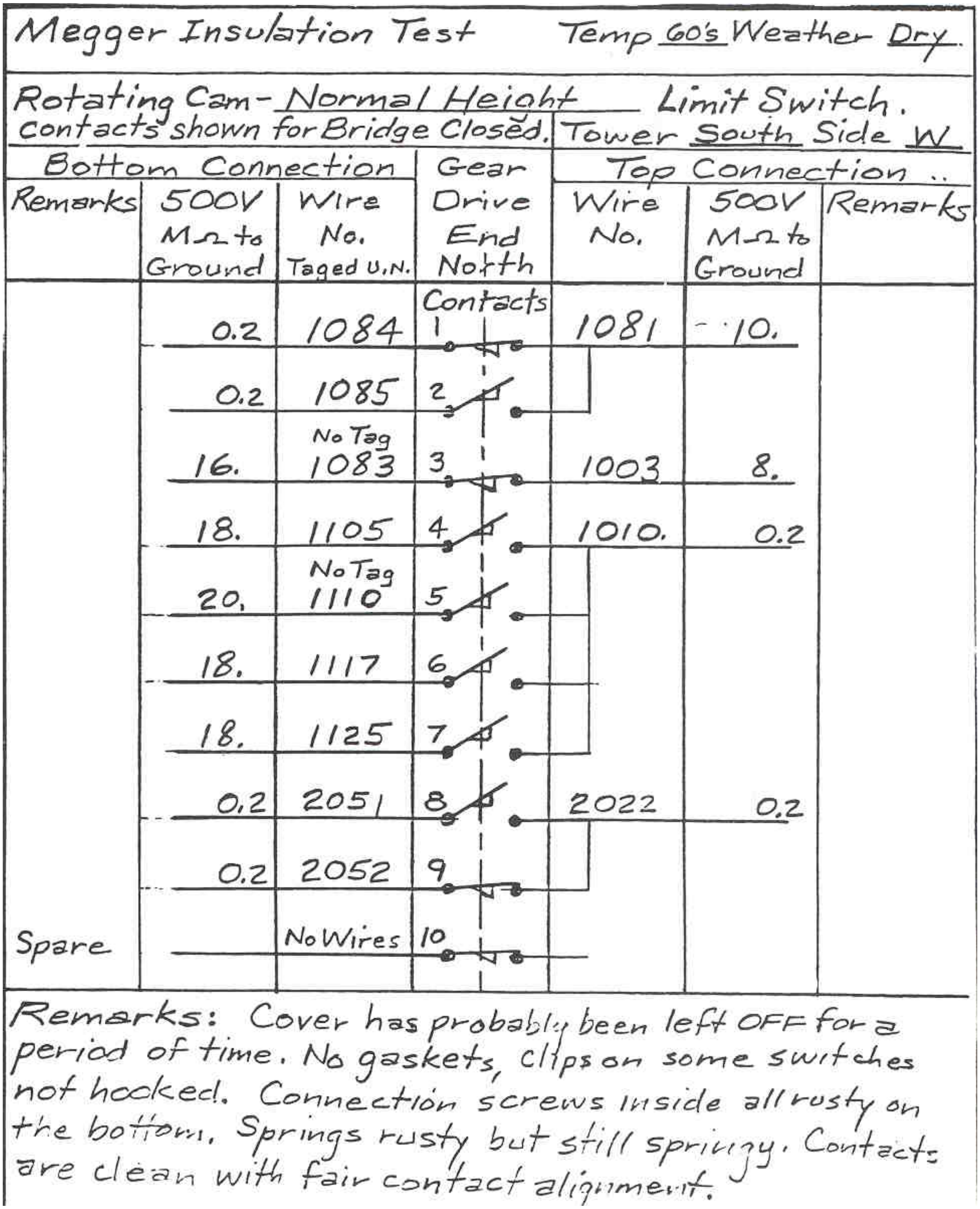
Item	General Condition
Housing Cover	Very good condition. Cover has four hinged maintenance panels, secured with studs and wingnuts. Cover bolted to lower supports with 20 bolts.
Normal (Main) Drive Clutch Cone	Very good condition. No slippage during span operation, starting or stopping. Clutch cone is inside differential assembly and impossible to inspect without disassembly of differential.
Emergency Drive Clutch Cone Assembly	Very good condition. Design plans show cone type clutch. Actually have jaw type clutch.
Differential Clutch Operating Linkage	Very good condition. Well lubricated. Linkage operates smooth and quiet.
Emergency Drive Clutch Operating Linkage	Very good condition. Well lubricated. Linkage operates smooth and quiet.
Gear Motor for operation of Differential Clutch	Good condition. Operates smoothly. Operated with hand crank, turned fairly easy. GE AC Gearmotor, Model KY3AC2345, Motor 1800 rpm, 1/8 HP, 250:1 ratio
Support for above Gear Motor	Good. Some debris and oil on support.
Gear Motor for operation of Emer. Drive Clutch	Good. Operates smoothly. Turned easily with hand crank. Same gearmotor as at differential clutch
Support for above Gear Motor	Good. Some debris and oil on support.
Housing Support	Good condition. Some debris and oil on support and floor. Paint good. 2 lights attached to supports inside

Figure 12.2.71 Example of Notes on Operating Machinery (Mechanical Elements)

Electrical Equipment 125HP, 600RPM, 3φ, 60H	
Motor A (Normal-Traction) Tower South - Side W	
General Items	General Condition
Stiffness of Supports	Good
Connection to "	Bolts tight
Condition of Frame	Dirty & Dusty Inside & out
Inspection Covers	Wire Mesh, 2 on Top (2 on Bott. missing)
Gaskets on "	None
Bolts on "	Tight
Ventilation	Open Ends
Operation-Noise	Normal
" -Vibration	Minimal
" -Bearings	Normal wear
Lubrication	Needs normal application
Oil-Dirt Build-Up	None (Except at couplings)
Insulation	See Megger test
Cable Connections	Good

Wound Rotor Motors	Wire No.	Raising Span Amps.	Lowering Span Amps.	
Motor Current - φ A	T1A	10-25-80 122	91	
B	T3A	124	93	
C	T2A	124	92	
Motor Voltage - A-B				460V
A-C				
B-C				
Rings - Surface	Normal wear			
" -Arcing	None Visible			
Brushes - Contact	Good			
" -Spring Pressure	Good, Springs Rusty			
" -Condition	Good, 2¼" length			
Wiring-Connection	Tight, Bolts Rusty			
" -Insulation	Good			
Rotor Current 3 φ A	M1A	10-25-80 50	31	
B	M3A	48	32	
C	M2A	50	32	

Figure 12.2.72 Example of Notes on Electrical Equipment (Motors)



Megger Insulation Test   Temp 60's Weather Dry.

Rotating Cam - Normal Height   Limit Switch.
contacts shown for Bridge Closed.   Tower South Side W

Bottom Connection			Gear	Top Connection		
Remarks	500V MΩ to Ground	Wire No. Taged U.N.	Drive End North Contacts	Wire No.	500V MΩ to Ground	Remarks
	0.2	1084	1	1081	-·10.	
	0.2	1085	2			
	16.	No Tag 1083	3	1003	8.	
	18.	1105	4	1010.	0.2	
	20.	No Tag 1110	5			
	18.	1117	6			
	18.	1125	7			
	0.2	2051	8	2022	0.2	
	0.2	2052	9			
Spare		No Wires	10			

Remarks: Cover has probably been left OFF for a period of time. No gaskets, clips on some switches not hooked. Connection screws inside all rusty on the bottom. Springs rusty but still springy. Contacts are clean with fair contact alignment.

Figure 12.2.73 Example of Notes on Electrical Equipment (Limit Switch)

Megger Insulation Test of the Submarine Cables

Temp 50°s Weather Dry

Equipment Being Controlled	Wire No. on Plans	Emergency Cables: No. in Cable	Emergency Cables: 500V MΩ	Emergency Cables: Remarks	Normal Cables: No. in Cable	Normal Cables: 500V MΩ	Normal Cables: Remarks
North Tower Elev.	261	1	6		2	500	
	261	3	6		4	500	
	263	5	1.5		6	<.2	>20kΩ
	263	7	1.5		8	.1	
	262	9	.9		10	.1	
	262	11	.9		12	.1	
Service Brake C	447	13	2.0		14	1000	
	446	15	40.		16	1000	
	448	17	15.		18	1000	
Service Brake D	467	19	2.		20	1000	
	466	21	25.		22	1000	
	468	23	5.		24	1000	
Drag Brake L	519	25	20.		26	1000	
	516	27	35.		28	1000	
	520	29	5.		30	1000	
Drag Brake M	529	31	4.		32	1000	
516	526	33	5.		34	1000	
	535	35	1.		36	1000	
North Lock Motor	617	37	0.8		38	1000	
	616	39	10.		40	1000	
	618	41	0.2		42	1000	
North Barrier Gate Motor	647	43	12.		44	1000	
	646	45	.7		46	1000	
	648	47	90		48	∞	
N.W. Traffic Gate Motor	687	49	.2		50	1000	
	686	51	35.		52	∞	
	688	53	100.		54	∞	
N.E. Traffic Gate Motor	697	55	9.		56	1000	
	696	57	6.		58	1000	
	698	59	3.		60	1000	

Figure 12.2.74 Example of Notes on Electrical Equipment (Megger Insulation Test of the Submarine Cables)

12.2.18 Evaluation

State and federal rating guidelines systems have been developed in order to aid in the inspection of movable bridges. The two major rating guidelines systems currently in use include the National Bridge Inspection Standards (NBIS) rating and the PONTIS Bridge Management System (BMS).

Application of the NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure (Item 59). Rating codes range from 9 to 0 where 9 is the best rating possible. See Section 4.2.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for appropriate movable bridge member. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. Element Level Smart Flags are also used to describe the condition of the steel superstructure both unpainted and painted.

In an element level condition state assessment of a movable bridge, the AASHTO CoRe element is:

Element No.	Description
101	Unpainted Steel Closed Web/Box Girder
102	Painted Steel Closed Web/Box Girder
106	Unpainted Steel Open Girder/Beam
107	Painted Steel Open Girder/Beam
112	Unpainted Steel Stringer(Stringer-Floorbeam System)
113	Painted Steel Stringer(Stringer-Floorbeam System)
120	Unpainted Steel Thru truss (Bottom Chord)
121	Painted Steel Thru truss (Bottom Chord)
125	Unpainted Steel Thru Truss (Excluding Bottom Chord)
126	Painted Steel Thru Truss (Excluding Bottom Chord)
130	Unpainted Steel Deck Truss
131	Painted Steel Deck Truss
140	Unpainted Steel Arch
141	Painted Steel Arch
151	Unpainted Steel Floorbeam
152	Painted Steel Floorbeam

The unit quantity for the superstructure is meters or feet and the total quantity must be placed in one of the available condition states. In both cases, Condition State 1 is the best possible rating. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements for condition state descriptions.

For damage due to fatigue, the “Steel Fatigue” Smart Flag, Element No. 356, can be used and one of the three condition states assigned. For rust, the “Pack Rust” Smart Flag, Element No. 357, can be used and one of the four condition states assigned. For damage due to traffic impact, the “Traffic Impact” Smart Flag, Element No. 362, can be used and one of the three condition states assigned. For movable bridges with section loss, the “Section Loss” Smart Flag, Element No. 363, can be used and one of the four condition states assigned.

For mechanical, electrical, and hydraulic movable bridge members, individual states may choose to create their own non-CoRe elements.

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Special Bridges

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Topic 12.3 Concrete Pipe Culverts

12.3.1 Introduction

A common type of culvert used today is the concrete pipe culvert (see Figure 12.3.1). The concrete pipe culvert is typically circular or elliptical in shape. The size of the opening of the pipe is determined by the peak flow of the channel. The circular shape is the most common shape manufactured for pipe culverts. It is hydraulically and structurally efficient under most conditions. Possible hydraulic drawbacks are that circular pipe generally causes some reduction in stream width during low flows. It may also be more prone to clogging than some other shapes. Elliptical shapes are used in situations where horizontal or vertical clearance is limited. The oblong shape allows the pipe to fit where a circular pipe may not, but still allows for the necessary size opening. Elliptical shaped pipe culverts may also be used when a wider section is desirable for low flow levels. As with circular shaped pipe culverts, these shapes also are prone to clogging as the depth of flow increases. In situations where the required size of the opening is very large, two or more concrete pipe culverts may be used (see Figure 12.3.2).

Figure 12.3.1 Concrete Pipe Culvert

Culverts are somewhat protected by the soil backfill from rapid fluctuations in surface temperature and direct application chloride (salts) used for deicing. As a result they are generally more resistant to surface deterioration than concrete bridge elements. Concrete culverts are classified as rigid structures because they do not bend or deflect appreciably.

Figure 12.3.2 Twin Concrete Pipe Culvert

12.3.2 Design Characteristics

Structural Behavior

The load carrying capability of rigid culverts is essentially provided by the structural strength of the pipe itself and little benefit from the surrounding soil is required. When vertical loads are applied to rigid culverts, tension and compression zones are created (see Figure 12.3.3). Reinforcing steel is added to the tension zones to increase the tensile strength of the pipe. Shear stress in the haunch or "bell" area where the pipe sections are joined, can be critical for heavily loaded rigid pipe on hard foundations, especially if the pipe bed preparation is inadequate. Because rigid pipe is stiffer than the surrounding soil, it carries a substantial portion of the load.

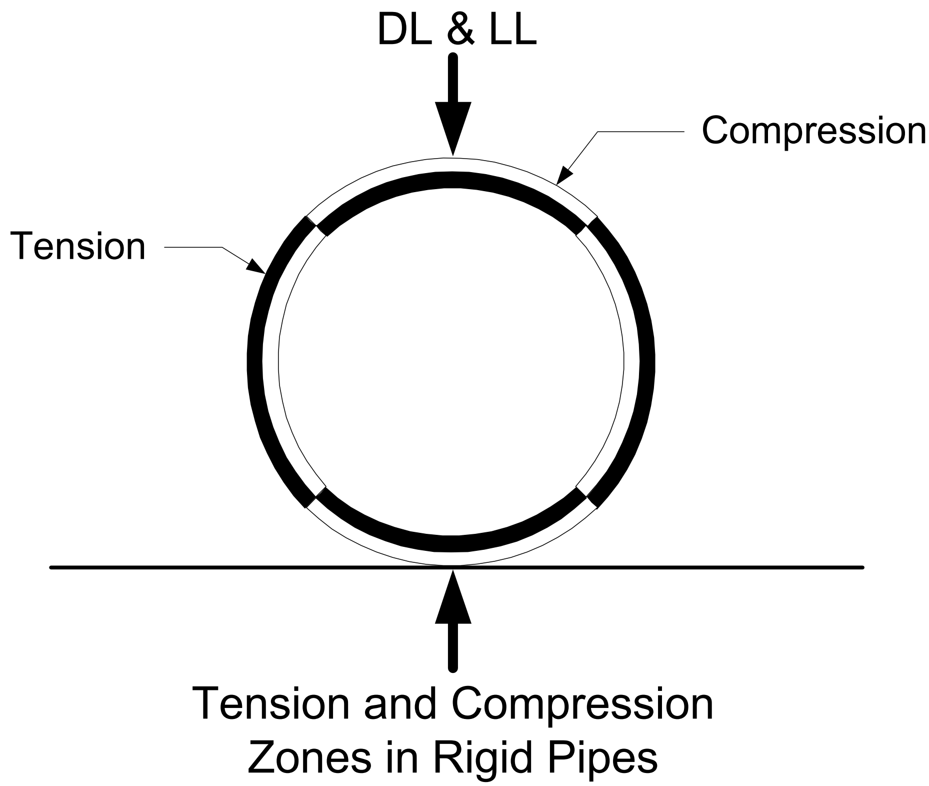


Figure 12.3.3 Rigid Culvert Stresses

The weight of earth that must be carried varies with soil characteristics and installation conditions. The installation conditions can have a significant influence on the loads that must be carried by a rigid culvert. There are two major classes of installation conditions: 1) trench, where culverts are placed in natural ground or compacted fill with a controlled trench width and 2) embankment, where culverts are placed in or covered by an embankment.

In narrow trench installations, the pipe is placed in a relatively narrow trench and covered with backfill material. The backfill tends to settle more than the undisturbed soil beside the trench. Friction between the backfill material and the sides of the trench tends to help support the backfill material reducing the load on the pipe. In effect the width of the soil column over the pipe is decreased.

As the trench width increases, the effect of the friction at the sides of the trench is reduced and dead load on the pipe is increased. The amount that the loading is increased depends on trench width and the amount of backfill settlement, which is related to compaction. Poorly compacted soil will settle more than well compacted soil. In a trench that is too wide, poor compaction can result in an increase in the dead load on the pipe. Pipes placed in a shallow bedding on top of the original ground surface and then covered by the embankment material will have loads similar to the very wide trench. Pipes placed in trenches in the original ground prior to being covered by embankment have reduced earth loads similar to those described for the narrow trench installations.

12.3.3 Types and Shapes of Concrete Pipe Culverts

Concrete culvert pipe is manufactured in up to five standard strength classifications. Higher classification numbers indicate higher strength. All of these standard shapes are manufactured in a wide range of sizes. Circular and elliptical pipes are available with standard sizes as large as 3.7 meters (12 feet) in diameter, with larger sizes available for special designs. Several factors such as span length, vertical and horizontal clearance, peak stream flow and terrain determine which shape of pipe culvert is used.

Precast concrete pipe culverts are manufactured in three standard shapes:

- Circular
- Horizontal elliptical
- Vertical elliptical

See pages 12.3.18 – 12.3.20 for the different standard sizes for concrete pipe culvert shapes.

12.3.4 Hazards of Culvert Inspection

The bridge inspector should be alerted to the following hazards when inspecting a culvert.

- Inadequate ventilation
- Drowning
- Toxic chemicals
- Animals
- Quick conditions at the outlet
- Insufficient number of inspectors

Refer to Topic 3.2.5 for a detailed discussion of each hazard.

12.3.5 Overview of Common Defects

Some of the more common defects that are found in concrete pipe culverts are:

- Cracking
- Spalling
- Delaminations
- Efflorescence
- Section loss of exposed reinforcing bars
- Embankment erosion at culvert entrance and exit
- Roadway settlement
- Foundation Failure
- Scour / Undermining
- Misalignment
- Settlement of pipe sections

For a detailed discussion of concrete defects, see Topic 2.2.

12.3.6 Inspection Procedures and Locations

Safety is the most important reason that culverts should be inspected. For a more detailed discussion on reasons for inspecting culverts, see Topic P.3.1.

Previous inspection reports and as-built plans, when available, should be reviewed prior to, and possibly during, the field inspection. A review of previous reports will familiarize the inspector with the structure and make detection of changed conditions easier. A review will also indicate critical areas that need special attention and the possible need for special equipment.

A logical sequence for inspecting culverts helps ensure that a thorough and complete inspection will be conducted. In addition to the culvert components, the inspector should also look for highwater marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems. In this regard, the inspection of culverts is similar to the inspection of bridges.

For typical installations, it is usually convenient to begin the field inspection with general observations of the overall condition of the structure and inspection of the approach roadway. The inspector should select one end of the culvert and inspect the embankment, waterway, headwalls, wingwalls, and culvert barrel. The inspector should then move to the other end of the culvert. The following sequence is applicable to all culvert inspections:

- Review available information
- Observe overall condition
- Inspect approach roadway and embankment
- Inspect waterway (see Topic 11.2)
- Inspect end treatments
- Inspect culvert barrel

Procedures

Visual

The inspection of concrete for cracks, spalls, and other defects is primarily a visual activity. However, hammers can be used to detect areas of delamination. A delaminated area will have a distinctive hollow “clacking” sound when tapped with a hammer or revealed with a chain drag. A hammer hitting sound concrete will result in a solid "pinging" type sound.

Physical

If the inspector deems it necessary, core samples can be taken from the culvert and sent to a laboratory to determine the extent of any chloride contamination.

Many of the problems associated with concrete culverts are caused by corrosion of steel reinforcement. When the deterioration of a concrete member progresses to the point of needing rehabilitation, an in-depth inspection of the member is required to determine the extent, cause, and possible solution to the problem. Several techniques and methods are available, as described in Topic 2.2

Advanced Inspection Techniques

In addition, several advanced techniques are available for concrete inspection.

Nondestructive methods, described in Topic 13.2.1, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Electromagnetic methods
- Pulse velocity
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Other methods, described in Topic 13.2.7, include:

- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes and videoscopes
- Moisture content
- Reinforcing steel strength

Locations

Rigid culverts such as precast concrete pipe do not deflect appreciably before cracking or fracturing. As a result, shape inspections, while very important in flexible structures, are of little value in inspecting precast concrete culverts.

Although the need for soil stability and side support is obviously important with flexible pipe, it is less important with rigid pipe. However, adequate stability of the surrounding soil is necessary to prevent settlement around the culvert and to achieve load carrying capability. The inspector should therefore look for any indications of a lack of soil stability such as settlement or misalignment as well as signs of structural distress such as cracking. Descriptions of the types of distress to look for during inspection are provided in the following paragraphs. Guidelines for condition ratings of concrete pipe are included at the end of this Topic.

The following is a list of areas that should be inspected in concrete pipe culverts.

- Misalignment
- Joint Defects
- Cracks
- Spalls
- Slabbing
- Durability
- End Section Drop-off

Misalignment

Misalignment may indicate the presence of serious problems in the supporting soil. The vertical and horizontal alignment of the culvert barrel should be checked by sighting along the crown and sides of the culvert and by checking for differential movement or settlement at joints between pipe sections. Vertical alignment should be checked for sags, faulting, and heaving. The inspector should be aware that pipes are occasionally laid with a camber or a grade change (broken back grade) to allow for fill settlement.

Sags which trap water may aggravate settlement problems by saturating the supporting soil. Horizontal alignment should be checked for straightness or smooth curvature for those culverts constructed with a curved alignment. Alignment problems may be caused by improper installation, undermining, or uneven settlement of fill. The inspector should attempt to determine which of those problems is causing the misalignment. If undermining is determined to be the probable cause, maintenance forces should be notified since damage will continue until the problem is corrected. The inspector should also try to determine whether the undermining is due to piping, water exfiltration, or infiltration of backfill material. When the misalignment is due to improper installation or uneven settlement, repeat inspections may be needed to determine if the settlement is still progressing or has stabilized.

Joint defects

Joint defects are fairly common and can range from minor problems to problems that are serious in nature. Typical joint defects include leakage (exfiltration and infiltration), cracks, and joint separation. Past and current criteria should be reviewed as some agencies design culverts with open joints to perform as subdrains.

(1) Exfiltration - Exfiltration occurs when leaking joints allow water flowing through the pipe to leak into the supporting material. Many culverts are built with joints that are not watertight or with mortar joints that crack with minor deflection, movement, or settlement of the pipe sections. Minor leakage may not always be a significant problem unless soils are quite erosive. However, if leaking joints contribute to or cause piping, then serious misalignment of the culvert or even failure may result. Leaking joints may be detected during low flows by visual observation of the joints and by checking around the ends of the culvert for evidence of piping.

(2) Infiltration – Infiltration is the opposite of exfiltration. Many culverts are essentially empty except during peak flows. When the water table is higher than the culvert invert, water may seep into the culvert between storms. This infiltration of water can cause settlement and misalignment problems if it carries fine grained soil particles from the surrounding backfill. Infiltration may be difficult to detect visually in its early stages although it may be indicated by open joints, staining at the joints on the sides and top of the culvert, deposits of soil in the invert, or by

depressions over the culvert, as shown in exhibit 105.

(3) Cracks – Cracks in the joint area may be caused by improper handling during installation, improper gasket placement, and movement or settlement of the pipe sections. Cracked joints are more than likely not watertight even if gaskets were used. However, if no other problems are evident, such as differential movement between pipe sections, and the cracks are not open or spalling, they may be considered a minor problem to only be noted in the inspection report. Severe joint cracks are similar in significance to separated joints.

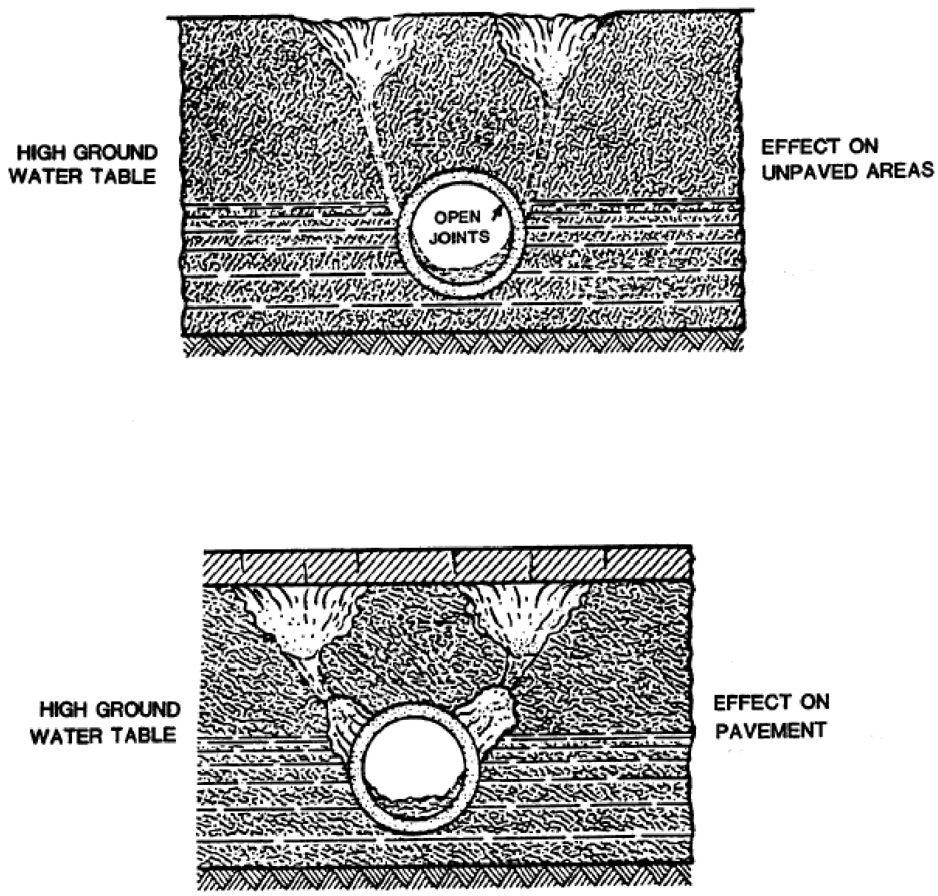


Figure 12.3.4 (Exhibit 105 – Culvert Inspection Manual, Report No. FHWA-IP-86-2) Surface Indications of Infiltration

(4) Separated Joints - Joint separations may be caused by the same forces described under misalignment (settlement, undermining, or improper installation). Joint separations are significant because they accelerate damage caused by exfiltration and infiltration resulting in the erosion of the backfill material. Examples of severe infiltration through separate joints are shown in exhibits 106 and 107. Separated joints are often found when severe misalignment is found. In fact either problem may cause or aggravate the other. Movement of the soil in the general direction of the culvert's centerline may cause sections

to gradually pull apart. Embankment slippage may also cause separations to occur.

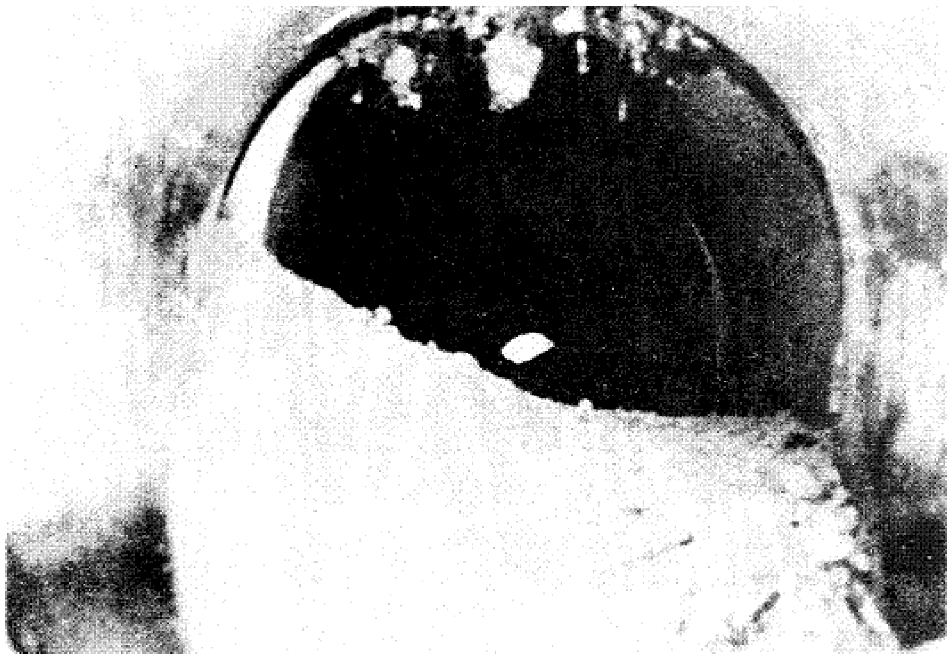


Figure 12.3.5 (Exhibit 106) Example of Severe Infiltration of Backfill Material through Separated Joints

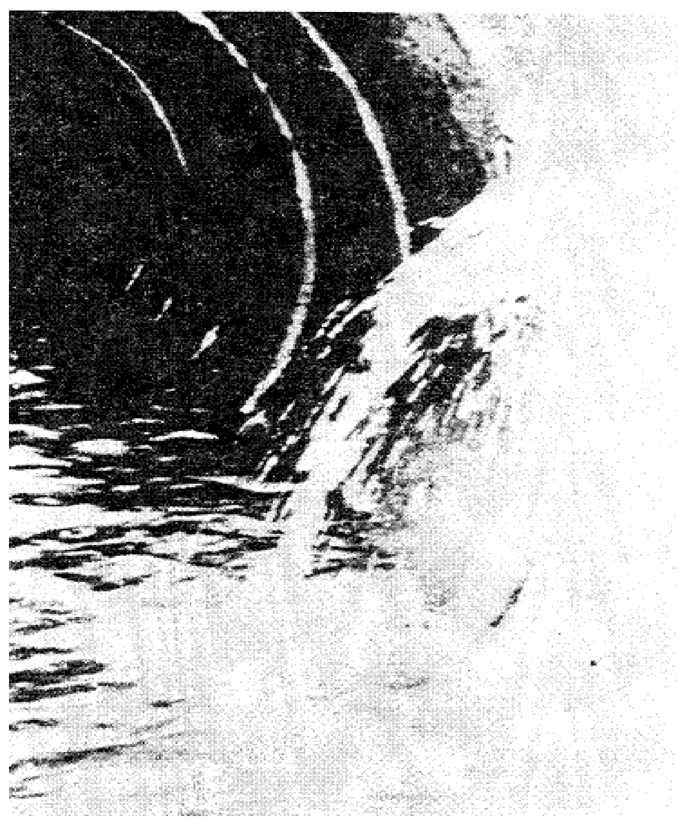


Figure12.3.6 (Exhibit 107) Severe Infiltration of Ground Water Through Separated Joint

Cracks

Longitudinal Cracks – Concrete is strong in compression but weak in tension. Reinforcing steel is provided to handle the tensile stresses. Hairline longitudinal cracks in the crown or invert indicate that the steel has accepted part of the load. Cracks less than 0.01 inches in width are minor and only need to be noted in the inspection report. Cracks greater than hairline cracks, or those more than 0.01 inch in width but less than 0.1 inches, should be described in the inspection report and noted as possible candidates for maintenance. Longitudinal cracking in excess of 0.1 inch in width may indicate overloading or poor bedding. If the pipe is placed on hard material and backfill is not adequately compacted around the pipe or under the haunches of the pipe, loads will be concentrated along the bottom of the pipe and may result in flexure or shear cracking, as illustrated in Figure 12.3.7.

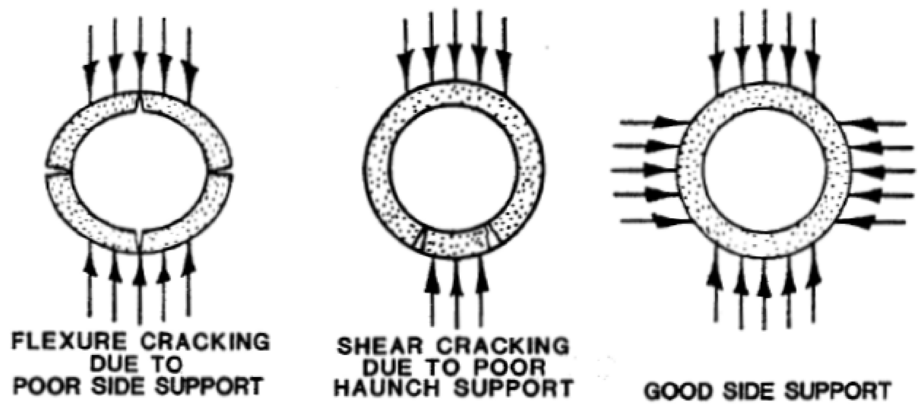


Figure 12.3.7 (Exhibit 108) Results of Poor and Good Side Support, Rigid Pipe

Other signs of distress such as differential movement, efflorescence, spalling, or rust stains should also be noted. Examples of longitudinal cracking are shown in Figures 12.3.8 and 12.3.9. When cracks are wider than 0.1 inch measurements should be taken of fill height and the diameter of the pipe both horizontally and vertically to permit analysis of the original design. Crack measurements and photographs may be useful for monitoring conditions during subsequent inspections.

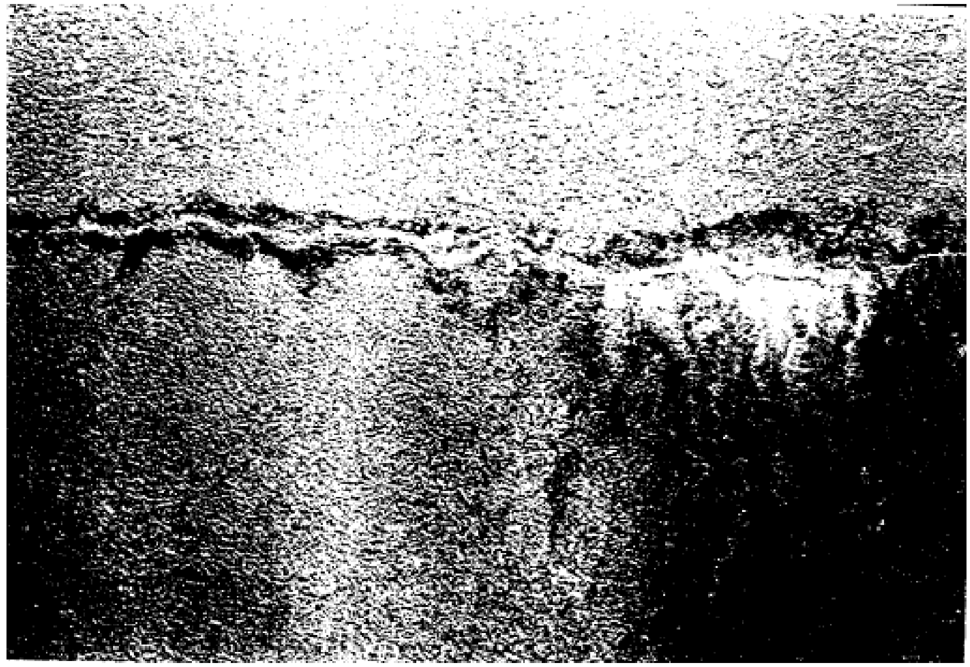


Figure 12.3.8 (Exhibit 108) Minor Longitudinal Crack with Efflorescence

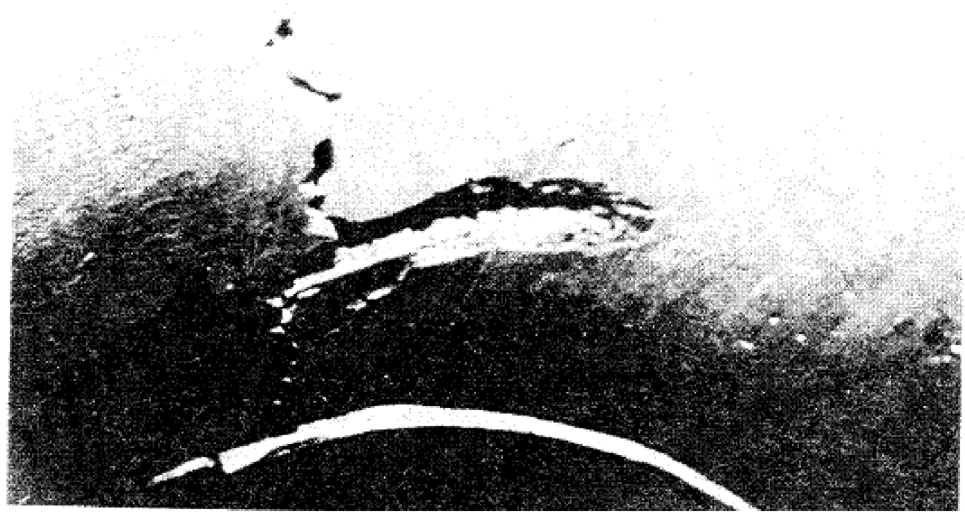


Figure 12.3.9 (Exhibit 110) Severe Longitudinal Cracks with Differential Movement and Spalling

Transverse Cracks – Transverse or circumferential cracks may also be caused by poor bedding. Cracks can occur across the bottom of the pipe (broken bell) when the pipe is only supported at the ends of each section. This is generally the result of poor installation practices such as not providing indentions (bell holes) in hard foundation material for the ends of bell and spigot-type pipe or not providing a sufficient depth of suitable bedding material. Cracks may occur across the top of pipe (broken back) when settlement occurs and rocks or other areas of hard foundation material near the midpoint of a pipe section are not adequately covered with suitable bedding material. Transverse cracking is illustrated in Figure 12.3.10.

Spalls

Spalling is a fracture of the concrete parallel or inclined to the surface of the concrete. In precast concrete pipe, spalls often occur along the edges of either longitudinal or transverse cracks when the crack is due to overloading or poor support rather than simple tension cracking. Spalling may also be caused by the corrosion of the steel reinforcing when water is able to reach the steel through cracks or shallow cover. As the steel corrodes, the oxidized steel expands, causing the concrete covering the steel to spall. Spalling may be detected by visual examination of the concrete along the edges of cracks. Tapping with a hammer should be performed along cracks to check for areas that have fractured but are not visibly separated. Such areas will produce a hollow sound when tapped. These areas may be referred to as delaminations or incipient spalls. Figure 12.3.11 shows spalling with reinforcing steel exposed.

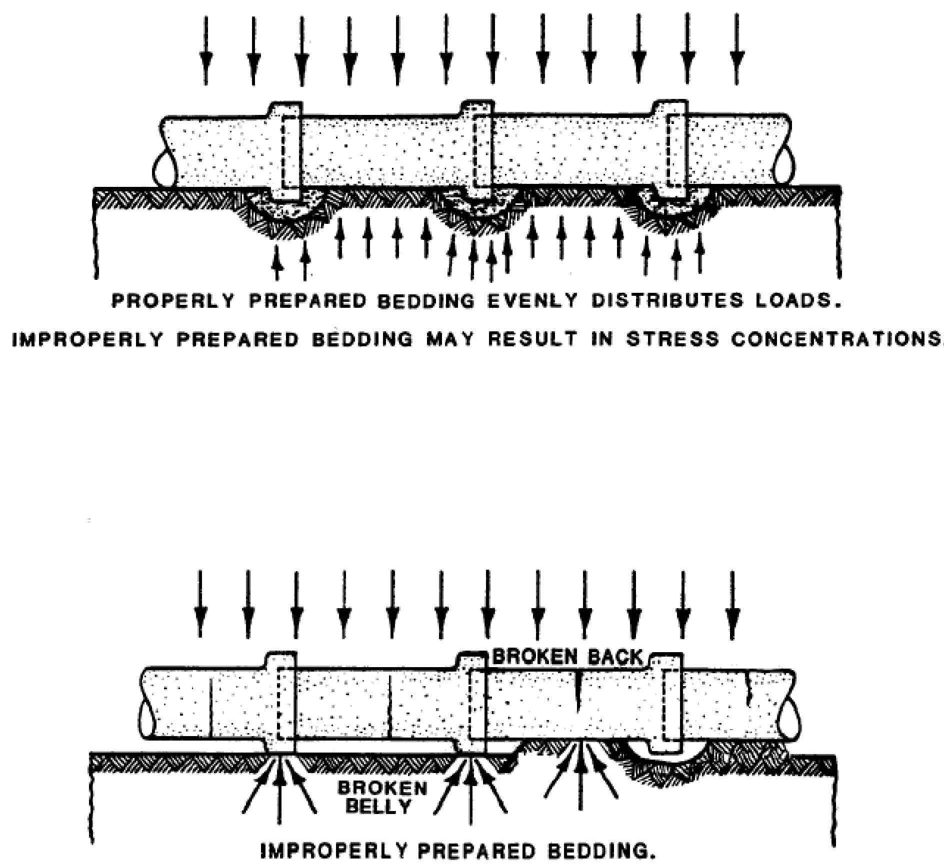


Figure 12.3.10 (Exhibit 111) Transverse or Circumferential Cracks

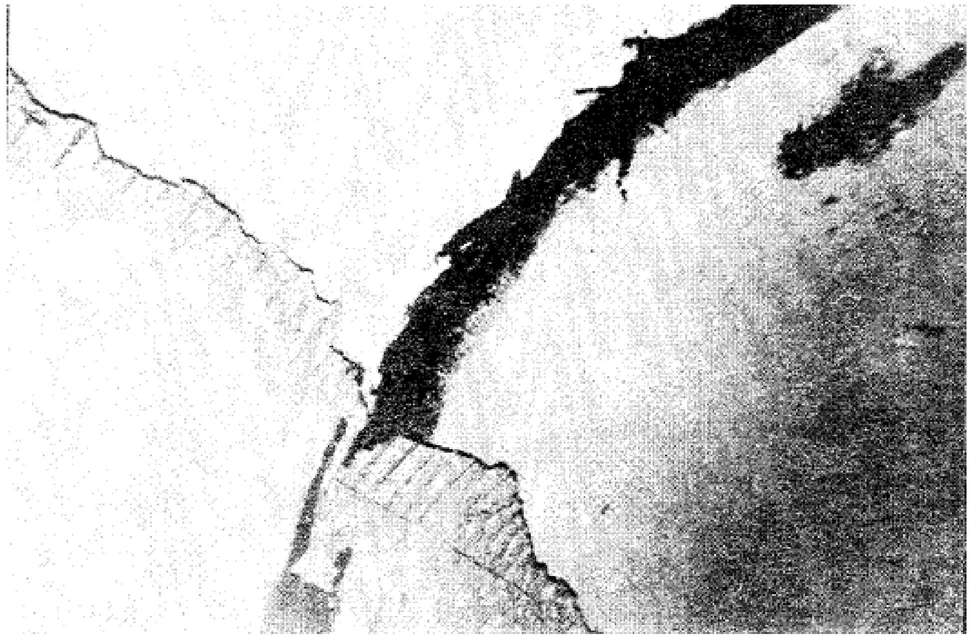


Figure 12.3.11 (Exhibit 112) Spalling Exposing Reinforcing Steel

Slabbing

The terms slabbing, shear slabbing, or slab shear refer to a radial failure of the concrete which occurs from straightening of the reinforcement cage due to excessive deflection. It is characterized by large slabs of concrete "peeling" away from the sides of the pipe and a straightening of the reinforcing steel as shown in Figure 12.3.12. Slabbing is a serious problem that may occur under high fills.

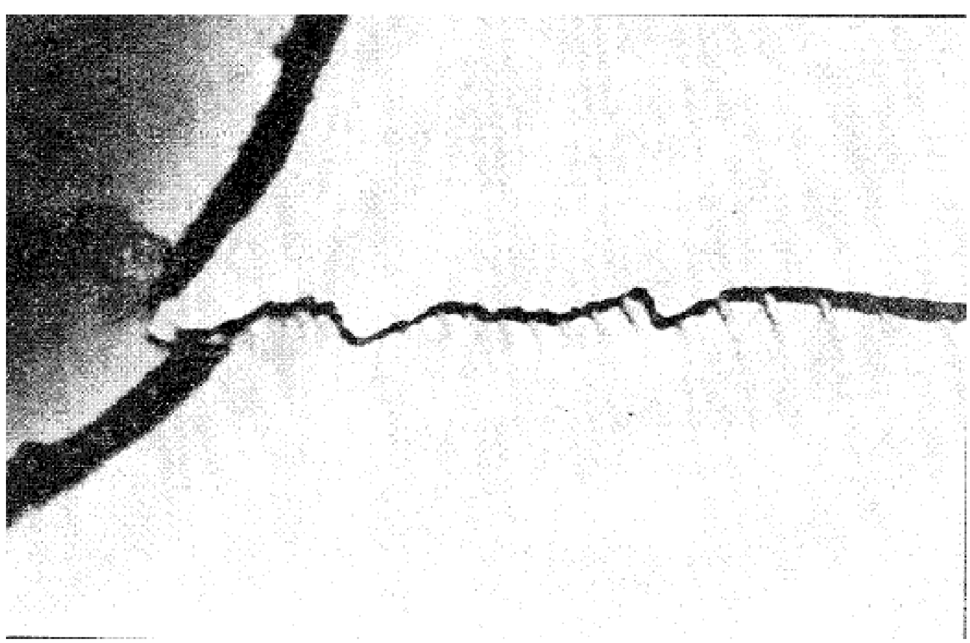


Figure 12.3.12 (Exhibit 113) Shear Slabbing

Durability

Durability is a measure of a culvert's ability to withstand chemical attack and abrasion. Concrete pipes are subject to chemical attack in strongly acidic environments such as drainage from mines and may also be damaged by abrasion. Abrasion damage is a wearing away of the concrete surface by sediment and debris being transported by the stream. Mild deterioration or abrasion less than 1/4 inch deep should be noted in the report. More severe surface deterioration should be reported as a potential candidate for maintenance. In severe cases where the invert is completely deteriorated, maintenance forces should be given immediate notification. When linings are used to protect against chemical attack or abrasion the condition of the lining should be noted in the report.

End Section Drop-off

This type of distress is usually due to outlet erosion as discussed earlier in the sections on end treatments and waterways. It is caused by the erosion of the material supporting the pipe sections on the outlet end of the culvert barrel.

RATING GUIDELINES FOR PRECAST CONCRETE PIPE CULVERT BARRELS

RATING	CONDITION
9	• New condition
8	• Alignment: good, no settlement or misalignment • Joints: tight with no defects apparent • Concrete: no cracking, spalling, or scaling present; surface in good condition
7	• Alignment: generally good; minor misalignment at joints; no settlement • Joints: minor openings, possible infiltration/exfiltration • Concrete: minor hairline cracking at isolated locations; slight spalling or scaling present on invert
6	• Alignment: fair, minor misalignment and settlement at isolated locations • Joints: minor backfill infiltration due to slight opening at joints; minor cracking or spalling at joints allowing exfiltration • Concrete: extensive hairline cracks, some with minor delaminations or spalling; invert scaling less than 0.25 in. deep or small spalls present
5	• Alignment: generally fair; minor misalignment or settlement throughout pipe; possible piping • Joints: open and allowing backfill to infiltrate; significant cracking or joint spalling • Concrete: cracking open greater than 0.12 in. with moderate delamination and moderate spalling exposing reinforcing steel at isolated locations; large areas of invert with surface scaling or spalls greater than 0.25 in. deep
4	• Alignment: marginal; significant settlement and misalignment of pipe; evidence of piping; end sections dislocated about to drop off • Joints: differential movement and separation of joints, significant infiltration or exfiltration at joints • Concrete: cracks open more than 0.12 in. with efflorescence and spalling at numerous locations; spalls have exposed rebars which are heavily corroded; extensive surface scaling on invert greater than 0.5 in.
3	• Alignment: poor with significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred • Joints: significant openings, dislocated joints in several locations exposing fill material; infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway • Concrete: extensive cracking, spalling, and minor slabbing; invert scaling has exposed reinforcing steel
2	• Alignment: critical; culvert not functioning due to alignment problems throughout • Concrete: severe slabbing has occurred in culvert wall, invert concrete completely deteriorated in isolated locations
1	• Culvert: partially collapsed • Road: closed to traffic
0	• Culvert: total failure of culvert and fill • Road: closed to traffic

NOTES:
1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.3.13 (Exhibit 114) Condition Rating Guidelines

Wingwalls

Wingwalls are provided to support the embankment around the openings of the culvert. Wingwalls should be inspected to ensure they are in proper vertical alignment. Wingwalls may be tilted due to settlement, slides or scour. See Topic 10.1 for a detailed description of defects and inspection procedures of wingwalls.

12.3.7 Evaluation

State and federal rating guidelines systems have been developed in order to aid in the inspection of concrete pipe culverts. The two major rating guidelines systems currently in use include the National Bridge Inspection Standards (NBIS) rating and the Element Level Bridge Management System (BMS).

Application of the NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the culvert (Item 62). This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. Rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2. The rating code is intended to be an overall evaluation of the culvert. Integral wingwalls to the first construction or expansion joint shall be included in the evaluation. It is also important to note that Items 58-Deck, 59-Superstructure, and 60-Substructure shall be coded "N" for all culverts.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the culvert. The information from the narrative and condition state summaries is then used to complete the element level condition report showing quantities at the correct rating value. There are no Element Level Smart Flags specific to culverts.

In an element level condition state assessment of a concrete pipe culvert, the AASHTO CoRe element is:

Element No.	Description
241	Reinforced Concrete Culvert

The quantity unit for culverts is meters or feet of culvert length along the barrel. The total quantity equals the culvert length times the number of barrels. The inspector must visually evaluate each 1 m (1 ft) slice of the culvert barrel(s) and assign the appropriate condition state description. See the AASHTO Guide for Commonly Recognized (CoRe) Structural Elements condition state assessment method for condition state descriptions.

The condition state descriptions for each slice are then compiled such that the total quantity of culvert is described by various quantities of culvert length distributed over a range of four condition state descriptions. The sum of the individual condition state quantities must equal the total element quantity.

Dimensions and Approximate Weights of Concrete Pipe

*ASTM C 76 – Reinforced concrete Culvert, Storm Drain and Sewer Pipe, Tongue and Groove Joints						
	WALL A		WALL B		WALL C	
Internal Diameter inches	**Minimum Wall Thickness, inches**	**Approximate Weight, pounds per foot**	**Minimum Wall Thickness, inches**	**Approximate Weight, pounds per foot**	**Minimum Wall Thickness, inches**	**Approximate Weight, pounds per foot**
96	8	2710	9	3090	9 ¾	3355
102	8 ½	3078	9 ½	3480	10 ¼	3760
108	9	3446	10	3865	10 ¾	4160

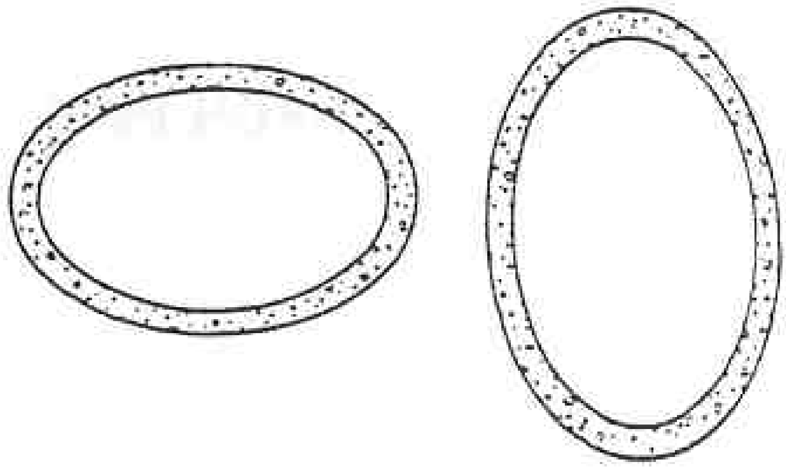
Large Sizes of Pipe Tongue and Groove Joint			
Internal Diameter Inches	**Internal Diameter Feet**	**Wall Thickness Inches**	**Approximate Weight, pounds per foot**
114	9 ½	9 ½	3840
120	10	10	4263
126	10 ½	10 ½	4690
132	11	11	5148
138	11 ½	11 ½	5627
144	12	12	6126
150	12 ½	12 ½	6647
156	13	13	7190
162	13 ½	13 ½	7754
168	14	14	8339
174	14 ½	14 ½	8942
180	15	15	9572

* For description of ASTM C 76 see page 12.3.20

Figure 12.3.14 Standard Sized for Concrete Pipe (Source: American Concrete Pipe Association)

Typical Cross Section of Arch Pipe

Horizontal and Vertical Ellipse Pipe



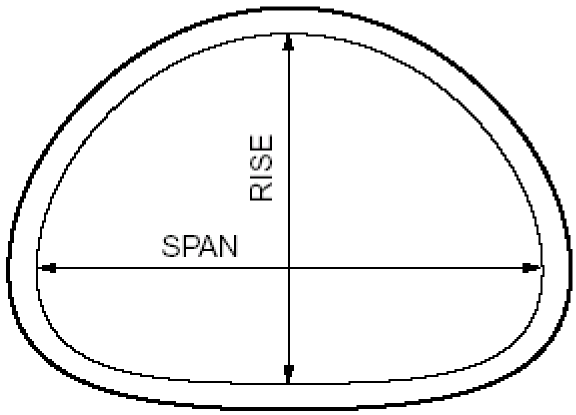
Dimensions and Approximate Weights of Elliptical Concrete Pipe

*ASTM C 507 – Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	**Minor Axis, inches**	**Major Axis, inches**	**Minimum Wall Thickness, inches**	**Water-Way Area, square feet**	**Approximate Weight, pounds per foot**
96	77	121	9 ½	52.4	3420
102	82	128	9 ¾	59.2	3725
108	87	136	10	66.4	4050
114	92	143	10 ½	74.0	4470
120	97	151	11	82.0	4930
132	106	166	12	99.2	5900
144	116	180	13	118.6	7000

* For description of ASTM C 507 see page 12.3.20

Figure 12.3.14 Standard Sized for Concrete Pipe (Source: American Concrete Pipe Association), continued

Typical Cross Section of Arch Pipe



Dimensions and Approximate Weights of Concrete Arch Pipe

*ASTM C 506 – Reinforced Concrete Arch Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	**Minimum Rise, inches**	**Minimum Span, inches**	**Minimum Wall Thickness, inches**	**Water-Way Area, square feet**	**Approximate Weight, pounds per foot**
96	77 1/4	122	9	51.7	3110
108	87 1/8	138	10	66.0	3850
120	96 7/8	154	11	81.8	5040
132	106 1/2	168 3/4	10	99.1	5220

* For description of ASTM C 506 see page 12.3.20

Figure 12.3.14 Standard Sized for Concrete Pipe (Source: American Concrete Pipe Association), continued

American Society for Testing and Materials (ASTM) descriptions for select rigid pipe culverts

ASTM C 76 Reinforced concrete Culvert, Storm Drain, and Sewer Pipe: Covers reinforced concrete pipe intended to be used for the conveyance of sewage, industrial wastes, and storm waters, and for the construction of culverts. Class I – 60 inches through 144 inches in diameter; Class II, III, IV and V – 12 inches through 144 inches in diameter. Larger sizes and higher classes are available as special designs.

ASTM C 506 Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe: Covers pipe to be used for the conveyance of sewage, industrial waste, and storm water and for the construction of culverts in sizes from 15 inch through 132 inch equivalent circular diameter. Larger sizes are available as special designs.

ASTM C 507 Reinforced Concrete Elliptical Culvert, Storm Drain, and Sewer Pipe: Covers reinforced elliptically shaped concrete pipe to be used for the conveyance of sewage, industrial waste and storm water, and for the construction of culverts. Five standard classes of horizontal elliptical, 18 inches through 144 inches in equivalent circular diameter and five standard classes of vertical elliptical, 36 inches through 144 inches in equivalent circular diameter are included. Larger sizes are available as special designs.

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Chapter 12
Special Bridges

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Topic 12.4 Flexible Culverts

12.4.1 Introduction

Like all culverts, flexible culverts are designed for full flow. Unlike bridges, culverts have no distinction between substructure and superstructure and because earth backfill separates the culvert structure from the riding surface, culverts have no "deck." Most flexible culverts have a circular or elliptical configuration but some flexible box and arch culverts exist. From their design nature, flexible culverts have little structural bending strength on their own. The material from which they are made, such as corrugated steel or aluminum can be flexed or bent and can be distorted significantly without cracking. Consequently, flexible culverts depend on the backfill support to resist bending. In flexible culvert designs, proper interaction between the soil and structure is critical.

This Topic discusses the characteristics, inspection, and evaluation of flexible culverts (see Figure 12.4.1).

Figure 12.4.1 Pipe Arch Flexible Culvert

12.4.2 Design Characteristics

Structural Behavior

A flexible culvert is a composite structure made up of the culvert barrel and the surrounding soil. The barrel and the soil are both vital elements to the structural performance of the culvert.

Flexible pipe has relatively little bending stiffness or bending strength on its own. Flexible culvert materials include steel, aluminum, and plastic. As loads are applied to the culvert, it attempts to deflect. In the case of a round pipe, the vertical diameter decreases and the horizontal diameter increases (see Figure 12.4.2). When good embankment material is well compacted around the culvert, the increase in horizontal diameter of the culvert is resisted by the lateral soil pressure. With round pipe the result is a relatively uniform radial pressure around the pipe which creates a compressive thrust in the pipe walls. As illustrated in Figure P.3.23, the compressive thrust is approximately equal to vertical pressure times one-half the span length.

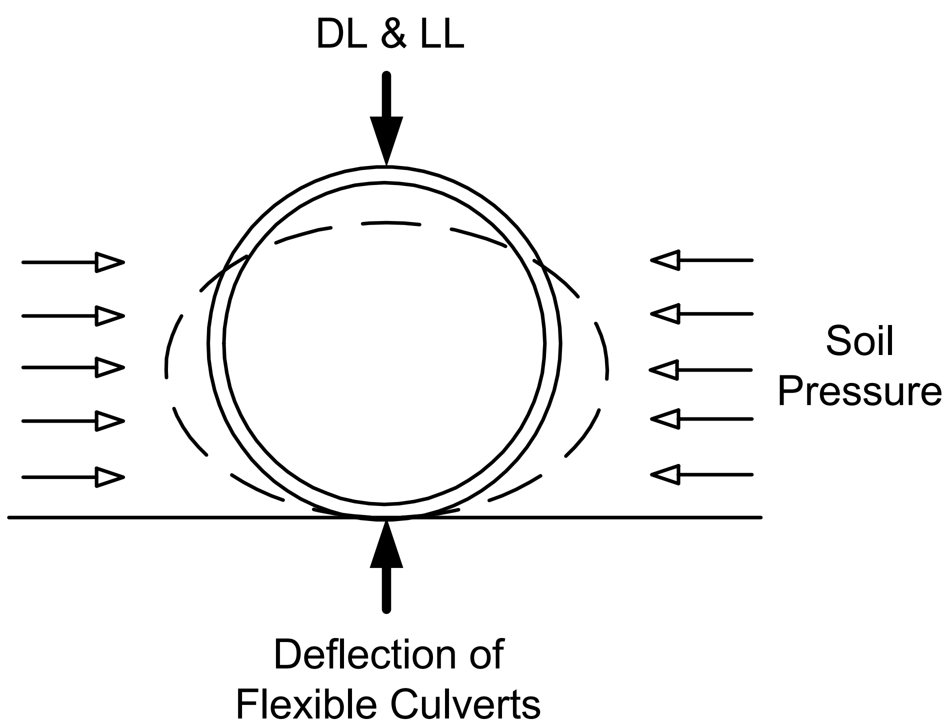
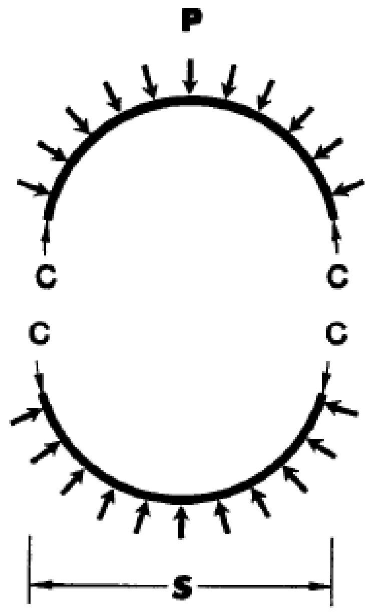


Figure 12.4.2 Flexible Culvert Deflection



SUMMING THE VERTICAL FORCES ON HALF OF THE PIPE AT A TIME SHOWS THAT

$$C = P \times \frac{S}{2}$$

WHERE

C= COMPRESSIVE THRUST IN THE CULVERT WALL

P= SUM OF SOIL PRESSURE ACTING ON THE CULVERT

S= THE SPAN OR DIAMETER

$\frac{S}{2}$= THE RADIUS (R)

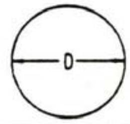
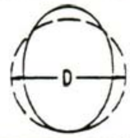
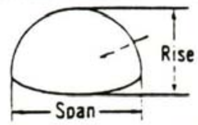
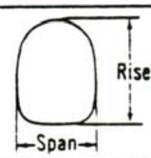
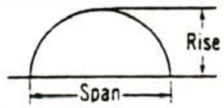
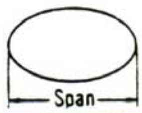
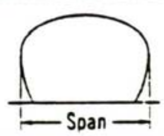
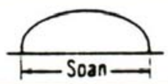
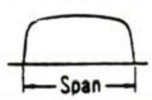
Figure 12.4.3 Formula for Ring Compression

An arc of a flexible round pipe, or other shape will be stable as long as adequate soil pressures are achieved, and as long as the soil pressure is resisted by the compressive force C on each end of the arc. Good quality backfill material and proper installation are critical in obtaining a stable soil envelope around a flexible culvert.

In long span culverts the radius (R) is usually large. To prevent excessive deflection due to dead and/or live loads, longitudinal or circumferential stiffeners are sometimes added. The circumferential stiffeners are usually metal ribs bolted to the outside of the culvert. Longitudinal stiffeners may be metal or reinforced concrete. Concrete thrust beams provide some circumferential stiffening as well as longitudinal stiffening. The thrust beams are added to the structure prior to backfill. They also provide a solid vertical surface for soil pressures to act on and a surface which is easier to backfill against. The use of concrete stress relieving slabs is another method used to achieve longer spans or reduce minimum cover. A stress-relieving slab is cast over the top of the backfill above the structure to distribute live loads to the adjacent soil.

12.4.3 Types and Shapes of Flexible Culverts

Flexible culverts are constructed from corrugated steel or aluminum pipe or field assembled structural plate products. Structural plate steel products are available as structural plate pipes, box culverts, or long span structures. See Figure 12.4.4 for standard shapes for corrugated flexible culverts.

Shape		Range of Sizes	Common Uses
Round		6 in – 26 ft	Culverts, subdrains, sewers, service tunnels, etc. All plates same radius. For medium and high fills (or trenches).
Vertically-elongated (ellipse) 5% is common		4–21 ft nominal: before elongating	Culverts, sewers, service tunnels, recovery tunnels. Plates of varying radii; shop fabrication. For appearance and where backfill compaction is only moderate.
Pipe-arch		Span x Rise 18 in. x 11 in. to 20 ft 7 in. x 13 ft 2 in.	Where headroom is limited. Has hydraulic advantages at low flows. Corner plate radius, 18 inches or 31 inches for structural plate.
Underpass*		Span x Rise 5 ft 8 in. x 5 ft 9 in. to 20 ft 4 in. x 17 ft 9 in.	For pedestrians, livestock or vehicles (structural plate).
Arch		Span x Rise 6 ft x 1 ft 9½ in. to 25 ft x 12 ft 6 in.	For low clearance large waterway opening, and aesthetics (structural plate).
Horizontal Ellipse		Span 20–40 ft	Culverts, grade separations, storm sewers, tunnels.
Pear		Span 25–30 ft	Grade separations, culverts, storm sewers, tunnels.
High Profile Arch		Span 20–45 ft	Culverts, grade separations, storm sewers, tunnels, Ammo ammunition magazines, earth covered storage.
Low Profile Arch		Span 20–50 ft	Low-Wide waterway enclosures, culverts, storm sewers.
Box Culverts		Span 10–21 ft	Low-wide waterway enclosures, culverts, storm sewers.
Specials		Various	For lining old structures or other special purposes. Special fabrication.

*For equal area or clearance, the round shape is generally more economical and simpler to assemble.

Figure 12.4.4 (Exhibit 11 Culvert Inspection Manual Report No. FHWA-IP-86-2) Standard Corrugated Steel Culvert Shapes (Source: Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute)

Corrugated Pipe

Factory-made pipe is produced in two basic shapes: round and pipe arch. Both shapes are produced in several wall thicknesses, several corrugation sizes, and with annular (circumferential) or helical (spiral) corrugations. Pipes with helical corrugations have continuously welded seams or lock seams. Both round and arch steel pipe shapes are available in a wide range of standard sizes. Round pipe is available in standard sizes up to 3.7 m (12 feet) in diameter. Standard sizes for pipe arch are available in sizes up to the equivalent of a 3 m (10 feet) diameter round pipe. Round aluminum pipe is available in standard sizes up to3 m (10 feet) in nominal diameter. Aluminum pipe arch is available in sizes up to the equivalent of an 2.4 m (8 feet) diameter round pipe.

Flexible aluminum culverts are constructed from factory assembled corrugated aluminum pipe or field assembled from structural plates. Structural plate aluminum culverts are available as conventional structural plate structures, box culverts, or long span structures.

Structural Plate

Structural plate steel pipes are field assembled from standard corrugated galvanized steel plates. Standard plates have corrugations with a 150 mm (6-inch) pitch and a depth of 50 mm (2 inches). Plates are manufactured in a variety of thicknesses and are pre-curved for the size and shape of structure to be erected.

Structural steel plate pipes are available in four basic shapes:

- Round
- Pipe arch
- Arch
- Underpass

The standard sizes available range in span from 1.5 to 7.9 m (5 feet to 26 feet).

Structural plate aluminum pipes are field assembled with a 230 mm (9-inch) pitch and a depth of 65 mm (2.5 inches).

Structural plate aluminum pipes are produced in five basic shapes:

- Round
- Pipe arch
- Arch
- Pedestrian/animal underpass
- Vehicle underpass

A wide range of standard sizes is available for each shape. Spans as large as 9.1 m (30 feet) can be obtained for the arch shape.

Box Culverts

Corrugated steel box sections use standard corrugated galvanized steel plates with special reinforcing elements applied to the areas of maximum moments. Steel box culverts are available with spans that range from to 2.9 to 6.3 m (9 feet 8 inches to 20 feet 9 inches).

The aluminum box culvert utilizes standard aluminum structural plates with aluminum rib reinforcing added in the areas of maximum bending stresses. Ribs are bolted to the exterior of the aluminum shell during installation. Aluminum box culverts are suitable for shallow depths of fill and are available with spans ranging from to 2.7 to 7.7 m (8 feet 9 inches to 25 feet 5 inches).

Long Span Culverts

Long span steel culverts are assembled using conventional 150 by 50 mm (6 by 2 inch) corrugated galvanized steel plates and longitudinal and circumferential stiffening members. There are five standard shapes for long span steel structures:

- Horizontal elliptical
- Pipe arch
- Low profile arch
- High profile arch
- Pear shape

The span lengths of typical sections range from 5.9 to 12.2 m (19 feet 4 inches to 40 feet). Longer spans are available for some shapes as special designs. It should be noted that each long span installation represents, to a certain extent, a custom design. The inspector should therefore use design or as-built plans when checking dimensions of existing long span structures.

Long span aluminum structures are assembled using conventional 230 by 65 mm (9 by 2 1/2 inch) corrugated aluminum plates and aluminum rib stiffeners. Long span aluminum structures are essentially the same size and available in the same five basic shapes as steel long spans.

See the end of this Topic for the different standard sizes for each flexible culvert shape (pg 164-193 Culvert Inspection Manual Report No. FHWA-IP-86-2)

12.4.4 Hazards of Culvert Inspection

The bridge inspector should be alert to the following hazards when inspecting a culvert.

- Inadequate ventilation
- Drowning
- Toxic chemicals
- Animals
- Quick conditions at the outlet
- Insufficient number of inspectors

Refer to Topic 3.2.5 for a detailed discussion of each hazard.

12.4.5 Overview of Common Defects

Common defects that can occur to flexible culvert materials include the following:

- Pitting
- Surface Rust
- Section Loss
- Overload Damage

- Heat Damage
- Buckling
- Embankment erosion at culvert entrance and exit
- Roadway settlement

Refer to Topic 2.3 for a more detailed presentation of the properties of steel, types and causes of steel deterioration, and the examination of steel.

12.4.6 Inspection Procedures and Locations

Safety is an important reason that culverts should be inspected. For a more detailed discussion on reasons for inspecting culverts, see Topic P.3.1.

A logical sequence for inspecting culverts helps ensure that a thorough and complete inspection will be conducted. In addition to the culvert components, the inspector should also look for highwater marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems. In this regard, the inspection of culverts is similar to the inspection of bridges.

For typical installations, it is usually convenient to begin the field inspection with general observations of the overall condition of the structure and inspection of the approach roadway. The inspector should select one end of the culvert and inspect the embankment, waterway, headwalls, wingwalls, and culvert barrel. The inspector should then move to the other end of the culvert. The following sequence is applicable to all culvert inspections:

- Review available information
- Observe overall condition
- Inspect approach roadway and embankment
- Inspect waterway (see in Topic 11.2)
- Inspect end treatments
- Inspect culvert barrel

Procedures

Visual

Most defects in flexible culverts are first detected by visual inspection. In order for this to occur, a hands-on inspection, or inspection where the inspector is close enough to touch the area being inspected, is required. The types of defects to look for when inspecting the culvert barrel will depend upon the type of culvert being inspected. In general, corrugated metal culvert barrels should be inspected for cross-sectional shape and barrel defects such as joint defects, seam defects, plate buckling, lateral shifting, missing or loose bolts, corrosion, excessive abrasion, material defects, and localized construction damage. A critical area for the inspection of long span metal culverts is at the 2 o'clock and 10 o'clock locations. An inward bulge at these locations may indicate potential failure of the structure.

Physical

In a steel culvert, the bolts on the longitudinal seams should be checked by tapping the nuts with a hammer. For aluminum structural plate, the bolts should be checked with a torque wrench.

A geologist's pick hammer can be used to scrape off heavy deposits of rust and scale. The hammer can then be used to locate areas of corrosion by striking the culvert walls. The walls will deform or the hammer will break through if severe corrosion exists.

Sometimes surveying the culvert is necessary to determine if there is any shape distortion, and if there is distortion how much exists.

Advanced Inspection Techniques

In steel culverts, visual inspections can only point out surface defects. Therefore, advanced inspection techniques may be used to achieve a more rigorous and thorough inspection of the steel culvert, including:

Nondestructive Testing Methods:

- Acoustic Emissions Testing
- Computer Programs
- Computer Tomography
- Corrosion Sensors
- Dye Penetrant
- Magnetic Flux Leakage
- Radiographic Testing
- Robotic Inspection
- Ultrasonic Testing
- Eddy Current

Other Testing Methods

- Brinell Hardness Test
- Charpy Impact Test
- Chemical Analysis
- Tensile Strength Test

See Topic 13.3 for Advanced Inspection Techniques

Locations

Inspect End Treatments

End treatments should be inspected like any other structural component. Their effectiveness can directly affect the performance of the culvert.

The most common types of end treatments for flexible culverts are:

- Projections
- Mitered
- Pipe end section

Projections - The inspector should indicate the location and extent of any undercutting around the ends of the barrel.

The depth of any scouring should be measured with a probing rod. In low flow conditions scour holes have a tendency to fill up with debris or sediment. If no probing rod is used an inspector could mistakenly report less scour than has taken place.

Water flowing along the outside of a culvert can remove supporting material. This is referred to as piping and it can lead to the culvert end being unsupported. If not repaired in time, piping can cause cantilevered end portions of the culvert to bend down and restrict the stream flow.

Mitered Ends - Inspection items for mitered ends are the same as for projecting ends. Additional care should be taken to measure any deformation of the end. Mitering the end of corrugated pipe culvert reduces its structural capacity.

Pipe End Sections - These are typically used on relatively smaller culverts. For inspection purposes, treat the pipe end section as you would a projected end.

The following excerpts are from a reproduction of the out-of-print Culvert Inspection Manual Report No.-IP-86-2 – Chapter 5, Section 4.

Section 4 - CORRUGATED METAL CULVERTS

5-4.0 General

Corrugated aluminum and corrugated steel culverts are classified as flexible structures because they respond to and depend upon the soil backfill to provide structural stability and support to the culvert. The flexible corrugated metal acts essentially as a liner. The liner acts mainly in compression and can carry large ring compression thrust, but very little bending or moment force. (Rib reinforced box culverts are exceptions.) Inspection of the culvert determines whether the soil envelope provides adequate structural stability for the culvert and verifies that the "liner" is capable of carrying the compressive forces and protecting the soil backfill from water flowing through the culvert. Verification of the stability of the soil envelope is accomplished by checking culvert shape. Verification of the integrity of the "liner" is accomplished by checking for pipe and plate culvert barrel defects.

This section contains discussions on inspecting corrugated metal structures for shape and barrel defects. Because shape inspection requirements do vary somewhat for different shapes, separate sections with detailed guidelines are provided for corrugated metal pipe culvert shapes and long-span culvert shapes. Section 5 of this chapter addresses corrugated metal pipe culverts, and section 6 covers long-span corrugated metal culverts.

5-4.1 Shape Inspections

The single most important feature to observe and measure when inspecting corrugated metal culverts is the cross-sectional shape of the culvert barrel. The corrugated metal culvert barrel depends on the backfill or embankment to maintain its proper shape and stability. When the backfill does not provide the required support, the culvert will deflect, settle, or distort. Shape changes in the culvert therefore provide a direct indication of the adequacy and stability of the supporting soil envelope. By periodic observation and measurement of the culvert's shape, it is possible to verify the adequacy of the backfill. The design or theoretical cross-section of the culvert should be the standard against which field measurements and visual observations are compared. If the design cross section is unknown, a comparison can be made between the unloaded culvert ends and the loaded sections beneath the roadway or deep fills. This can often provide an indication of structure deflection or settlement. Symmetrical shape and uniform curvature around the perimeter are generally the critical factors. If the curvature around the structure becomes too flat, and/or the soil continues to yield under load, the culvert wall may not be able to carry the ring thrust without either buckling inward or deflecting excessively to the point of reverse curvature. Either of these events leads to partial or total failure.

As explained in earlier in this Topic, an arc of a circular pipe or other shape structure will be stable and perform as long as the soil pressure on the outside of the pipe is resisted by the compression force in the pipe at each end of the arc.

Corrugated metal pipes can change shape safely within reasonable limits as long as there is adequate exterior soil pressure to balance the ring compression. Therefore, size and shape measurements taken at any one time do not provide conclusive data on backfill instability even when there is significant deviation from the design shape. Current backfill stability cannot be reliably determined unless changes in shape are measured over time. It is therefore necessary to identify current or recent shape changes to reliably check backfill stability. If there is instability of the backfill, the pipe will continue to change shape.

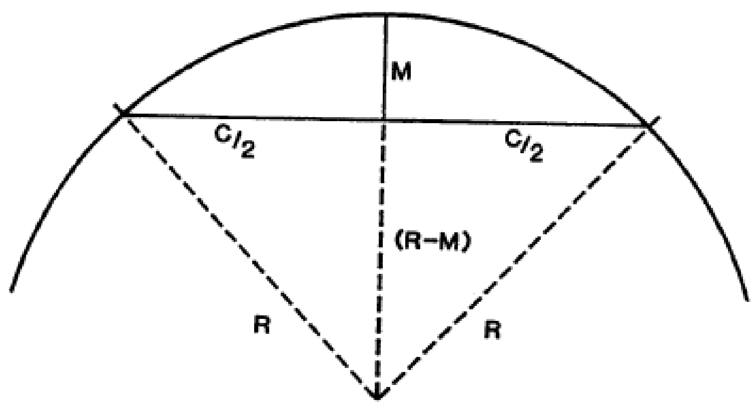
In general, the inspection process for checking shape will include visual observations for symmetrical shape and uniform curvature as well as measurements of important dimensions. The specific measurements to be obtained depend upon factors such as the size, shape, and condition of the structure. If shape changes are observed, more measurements may be necessary. For small structures in good condition, one or two simple measurements may be sufficient, for example, measuring the horizontal diameter on round pipe. For larger structures such as long span culverts, key measurements may be difficult to obtain. Horizontal diameters may be both high and large. The inspection process for long span culverts generally requires that elevations be established for key points on the structure. Although some direct measurements may also be required for long-span structures, elevations are needed to check for settlement and for calculating vertical distances such as the middle ordinate of the top arc. For structures with shallow cover, observations of the culvert with a few live loads passing over are recommended. Discernible movement in the structure may indicate possible instability and a need for more in-depth investigation.

The number of measurement locations depends upon the size and condition of the structure. Long-span culverts should normally be measured at the end and at 7.6 m (25 foot) intervals. Measurements may be required at more frequent intervals if significant shape changes are observed. The smaller pipe culverts can usually be measured at longer intervals than long-span culverts.

Locations in sectional pipe can be referenced by using pipe joints as stations to establish the stationing of specific cross-sections. Stations should start with number 1 at the outlet and increase going upstream to the inlet. The location of points on a circular cross section can be referenced like hours on a clock. The clock should be oriented looking upstream. On structural plate corrugated metal culverts, points can be referenced to bolted circumferential and longitudinal seams.

It is extremely important to tie down exact locations of measurement points. Unless the same point is checked on each inspection, changes cannot be accurately monitored. The inspection report must, therefore, include precise descriptions of reference point locations. It is safest to use the joints, seams, and plates as the reference grid for measurement points. Exact point locations can then be easily described in the report as well as physically marked on the structures. This guards against loss of paint or scribe marks and makes points easy to find or reestablish. All dimensions in structures should be measured to the inside crest of corrugation. When possible, measurement points on structural plate should be located at the center of a longitudinal seam. However, some measurement points are not on a seam.

When distortion or curve flattening is apparent, the extent of the flattened area, in terms of arc length, length of culvert affected, and the location of the flattened area should be described in the inspection report. The length of the chord across the flattened area and the middle ordinate of the chord should be measured and recorded. The chord and middle ordinate measurements can be used to calculate the curvature of the flattened area using the formula shown in exhibit 66.



C = MEASURED CHORD

M = MEASURED MIDDLE ORDINATE

SOLVE FOR R_A = ACTUAL RADIUS

$$R_A = \frac{4M^2 + C^2}{8M}$$

IF R_A IS > R_D (DESIGN RADIUS) THEN ACTUAL CURVE IS FLATTER THAN DESIGN

Figure 12.4.5 (Exhibit 66) Checking Curvature by Curve and Middle Ordinate

5-4.2 Inspecting Barrel Defects

The structural integrity of corrugated metal culverts and long-span structures is dependent upon their ability to perform in ring compression and their interaction with the surrounding soil envelope. Defects in the culvert barrel itself, which can influence the culvert's structural and hydraulic performance, are discussed in the following paragraphs. Rating guidelines are provided in the sections dealing with specific shapes.

a. Misalignment - The inspector should check the vertical and horizontal alignment of the culvert. The vertical alignment should be checked visually for sags and deflection at joints. Poor vertical alignment may indicate problems with the subgrade beneath the pipe bedding. Sags trap debris and sediment and may impede flow. Since most highway culverts do not have watertight joints, sags which pocket water could saturate the soil beneath and around the culvert, reducing the soil's stability. The horizontal alignment should be checked by sighting along the sides for straightness. Vertical alignment can be checked by sighting along bolt lines. Minor horizontal and vertical misalignment is generally not a significant problem in corrugated metal structures unless it causes shape or joint problems. Occasionally culverts are intentionally installed with a change in gradient.

b. Joint Defects - Field joints are generally only found with factory manufactured pipe. There are ordinarily no joints in structural plate culverts, only seams. (In a few cases, preassembled lengths of structural plate pipe have been coupled or banded together like factory pipe.)

Field joints in factory pipe serve to maintain the water conveyance of the culvert from section to section, to keep the pipe sections in alignment, keep the backfill soil from infiltrating, and to help prevent sections from pulling apart. Joint separation may indicate a lack of slope stability as described in section 5-4.2 e., circumferential seams. Key factors to look for in the inspection of joints are indications of backfill infiltration and water exfiltration. Excessive seepage through an open joint can cause soil infiltration or erosion of the surrounding backfill material reducing lateral support. Open joints may be probed with a small rod or flat rule to check for voids. Indications of joint defects include open joints, deflection, seepage at the joints, and surface sinkholes over the culvert as illustrated in exhibits 67 and 68. Any evidence of joint defects should be recorded. Culverts in good condition should have no open joints, those in fair condition may have a few open joints but no evidence of soil infiltration, and those in marginal to poor condition will show evidence of soil infiltration.

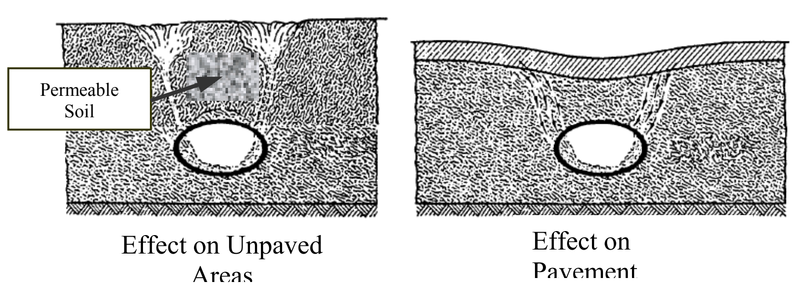


Figure 12.4.6 (Exhibit 67) Surface Indications of Infiltration

Figure 12.4.7 (Exhibit 68) Surface Hole Above Open Joint

c. Seam Defects in Fabricated Pipe - Pipe seams in helical pipe do not carry a significant amount of the ring compression thrust in the pipe. That is the reason that a lock seam is an acceptable seam. Helical seams should be inspected for cracking and separation. An open seam could result in a loss of backfill into the pipe, or exfiltration of water. Either condition could reduce the stability of the surrounding soil.

In riveted or spot welded pipes, the seams are longitudinal and carry the full ring compression in the pipe. These seams, then, must be sound and capable of handling high compression forces. They should be inspected for the same types of defects as those described in the text for structural plate culverts, Section 12.4.3, Structural Pipe. When inspecting the longitudinal seams of bituminous-coated corrugated metal culverts, cracking in the bituminous coating may indicate seam separation.

d. Longitudinal Seam Defects in Structural Plate Culverts - Longitudinal seams should be visually inspected for open seams, cracking at bolt holes, plate distortion around the bolts, bolt tipping, cocked seams, cusped seams, and for significant metal loss in the fasteners due to corrosion.

Culverts in good condition should have only minor joint defects. Those in fair condition may have minor cracking at a few bolt holes or minor opening at seams that could lead to infiltration or exfiltration. Marginal to poor culvert barrel conditions are indicated by significant cracking at bolt holes, or deflection of the structure due to infiltration of backfill through an open seam. Cracks 3 inches (76 mm) long on each side of the bolts indicate very poor to critical conditions.

(1) Loose Fasteners - Seams should be checked for loose or missing fasteners as shown in exhibit 69. For steel structures the longitudinal seams are bolted together with high-strength bolts in

two rows; one row in the crests and one row in the valleys of the corrugations. These are bearing type connections and are not dependent on a minimum clamping force of bolt tension to develop interface friction between the plates. Fasteners in steel structural plate may be checked for tightness by tapping lightly with a hammer and checking for movement.

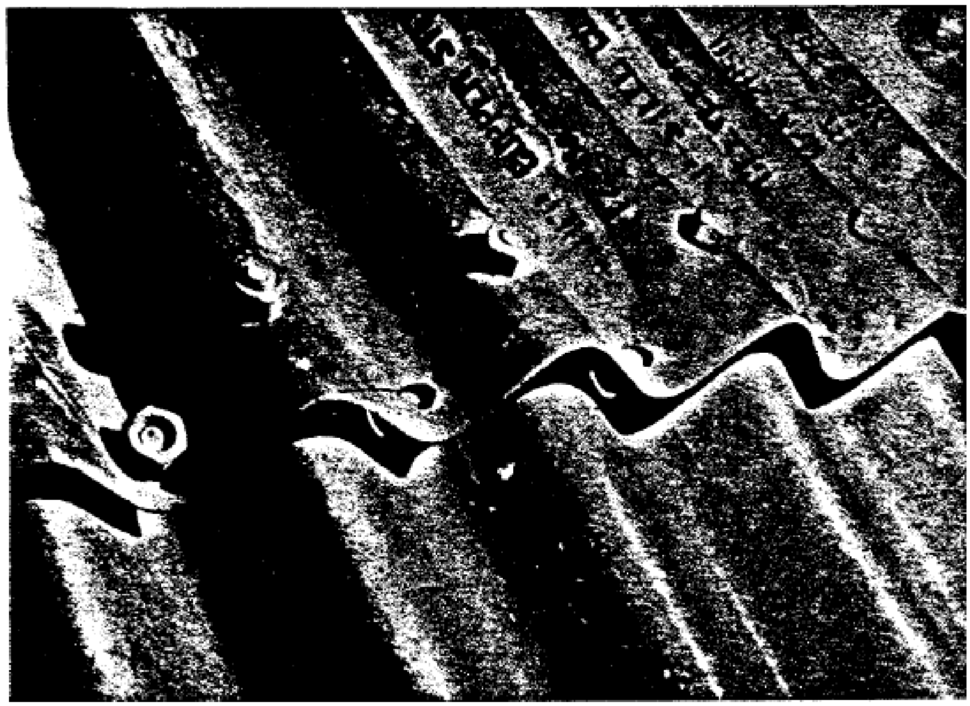


Figure 12.4.8 (Exhibit 69) Close-Up of Loose and Missing Bolts at a Cusped Seam; Loose Fasteners are Usually Detected by Tapping the Nuts with a Hammer

For aluminum structural plate, the longitudinal seams are bolted together with normal strength bolts in two rows with bolts in the crests and valleys of both rows. These seams function as bearing connections, utilizing bearing of the bolts on the edges of holes and friction between the plates. The seams in aluminum structural plate should be checked with a torque wrench (125 ft-lbs (169 Joules) minimum to 150 ft-lbs (203 Joules) maximum). If a torque wrench is not available fasteners can be checked for tightness with a hammer as described for steel plates.

(2) Cocked and Cusped Seams - The longitudinal seams of structural plate are the principal difference from factory pipe. The shape and curvature of the structure is affected by the lapped, bolted longitudinal seam. Improper erection or fabrication can result in cocked seams or cusped effects in the structure at the seam, as illustrated in exhibit 70. Slight cases of these conditions are fairly common and frequently not significant. However, severe cases can result in failure of the seam or structure. When a cusped seam is significant the structure's shape appearance and key dimensions will differ significantly from the design shape and dimensions. The cusp effect should cause the structure to receive very low

ratings on the shape inspection if it is a serious problem. A cocked seam can result in loss of backfill and may reduce the ultimate ring compression strength of the seam.

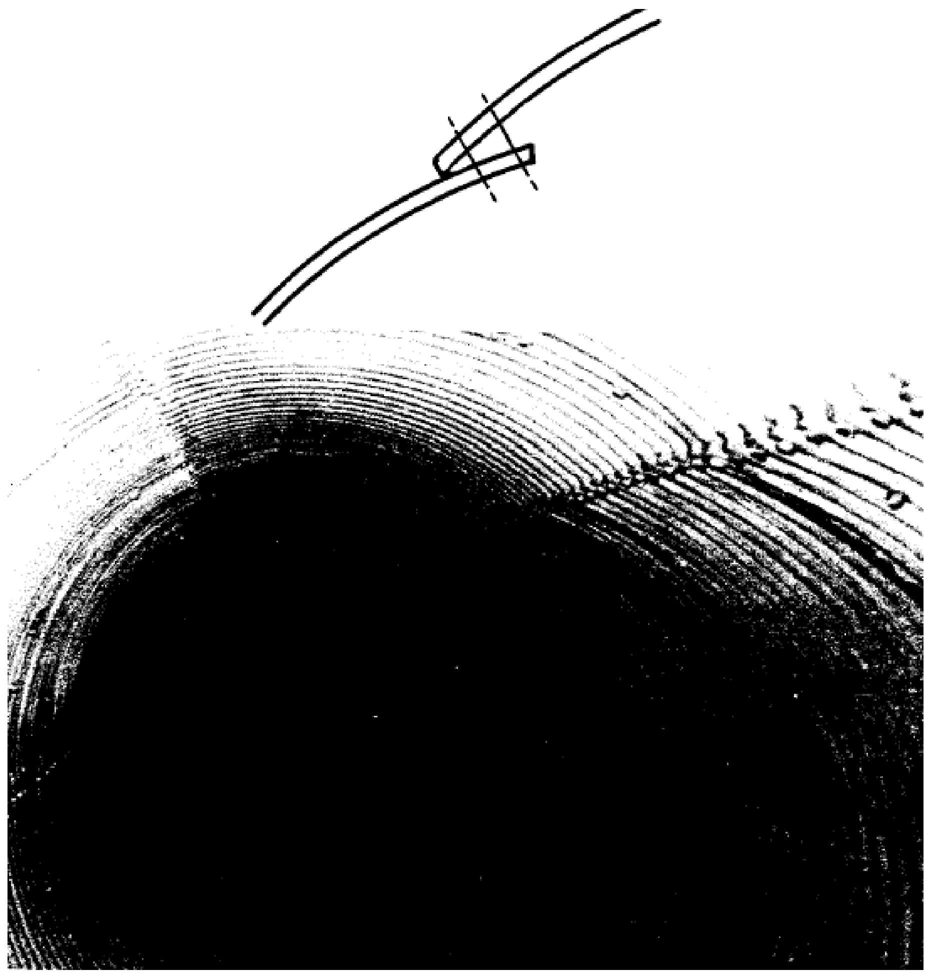


Figure 12.4.9 (Exhibit 70) Cocked Seam with Cusp Effect

(3) Seam Cracking - Cracking along the bolt holes of longitudinal seams can be serious if allowed to progress. As cracking progresses, the plate may be completely severed and the ring compression capability of the seam lost. This could result in deformation or possible failure of the structure. Longitudinal cracks are most serious when accompanied by significant deflection, distortion, and other conditions indicative of backfill or soil problems. Longitudinal cracks are caused by excessive bending strain, usually the result of deflection, exhibit 71. Cracking may occasionally be caused by improper erection practices such as using bolting force to "lay down" a badly cocked seam.

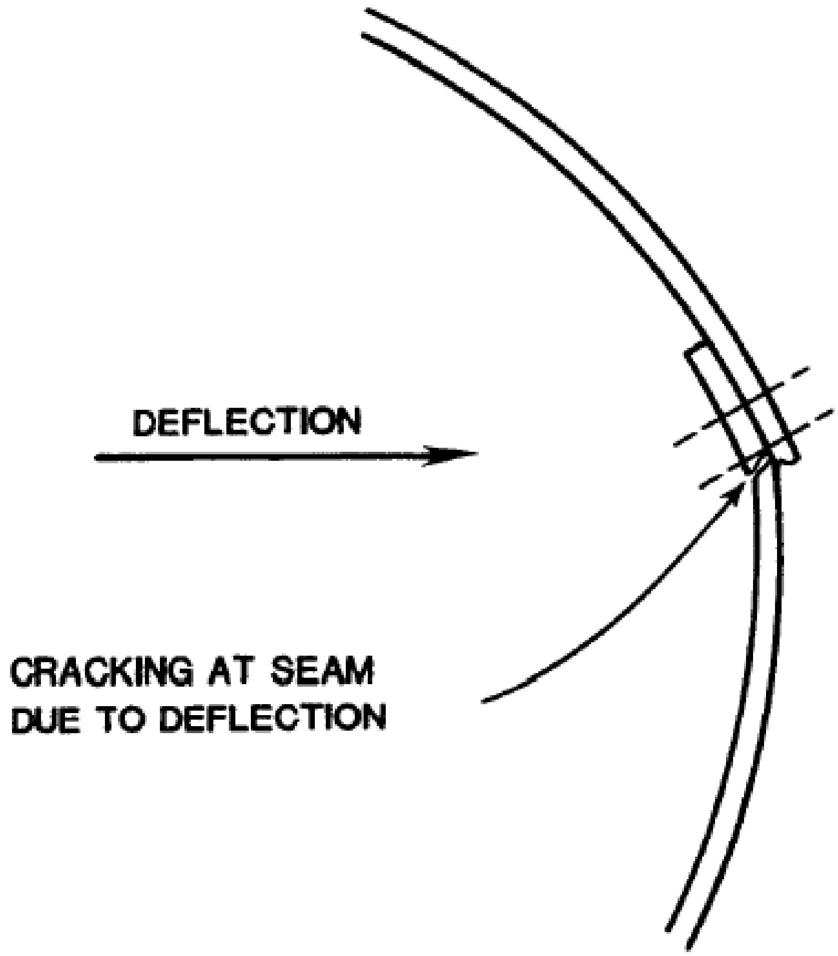


Figure 12.4.10 (Exhibit 71) Cracking Due to Deflection

(4) Bolt Tipping - The bolted seams in structural plate culverts only develop their ultimate strength under compression. Bolt tipping occurs when the plates slip. As the plates begin to slip, the bolts tip, and the bolt holes are plastically elongated by the bolt shank. High compressive stress is required to cause bolt tipping. Structures have rarely been designed with loads high enough to produce a ring compression that will cause bolt tip. However, seams should be examined for bolt tip particularly in structures under higher fills. Excessive compression on a seam could result in plate deformations around the tipped bolts and failure is reached when the bolts are eventually pulled through the plates.

e. Circumferential Seams - The circumferential seams, like joints in factory pipe, do not carry ring compression. They do make the conduit one continuous structure. Distress in these seams is rare and will ordinarily be a result of a severe differential deflection or distortion problem or some other manifestation of soil failure. For example, a steep sloping structure through an embankment may be pulled apart longitudinally if the embankment moves down as shown in exhibit 72. Plates should be installed with the upstream plate overlapping the downstream plate to provide a "shingle" effect in the direction of flow.

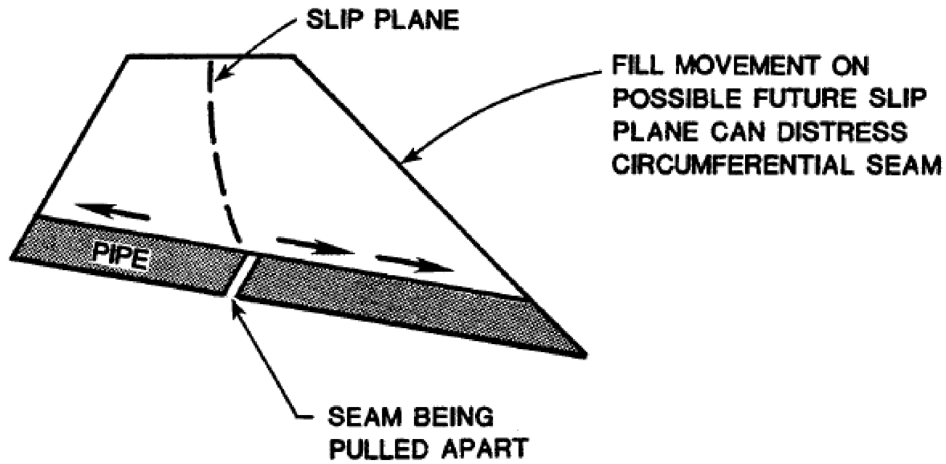


Figure 12.4.11 (Exhibit 72) Circumferential Seam Failure Due to Embankment Slippage

The circumferential seam at one or more locations would be distressed by the movement of the fill. Such distress is important to note during inspections since it would indicate a basic problem of stability in the fill. Circumferential seam distress can also be a result of foundation failure, but in such cases should be clearly evident by the vertical alignment.

f. Dents and Localized Damage - All corrugated metal culverts should be inspected for localized damage. Pipe wall damage such as dents, bulges, creases, cracks, and tears can be serious if the defects are extensive and can impair either the integrity of the barrel in ring compression or permit infiltration of backfill. Small, localized examples are not ordinarily critical. When the deformation type damages are critical, they will usually result in a poorly shaped cross section. The inspector should document the type, extent, and location of all significant wall damage defects. When examining dents in corrugated steel culverts, the opposite side of the plate should be checked, if possible, for cracking or disbonding of the protective coating.

g. Durability (Wall Deterioration) - Durability refers to the ability of a material to resist corrosion and abrasion. Corrosion is the deterioration of metal due to electrochemical or chemical reactions. Abrasion is the wearing away of culvert materials by the erosive action of bedload carried in the stream.

Abrasion is generally most serious in steep or mountainous areas where high flow rates carry sand and rocks that wear away the culvert invert. Abrasion can also accelerate corrosion by wearing away protective coatings.

As discussed in Section P.3.10 and P.3.11 of this manual, metal culverts are subject to corrosion in certain aggressive environments. For example, steel rapidly corrodes in salt water and in environments with highly acidic (low pH) conditions in the soil and water. Aluminum is fairly resistant to salt water but will corrode rapidly in highly alkaline (high pH) environments, particularly if metals such as iron or copper and their salts are present. The electrical resistivity of soil and water also provide an indication of the likelihood of corrosion. Many agencies have established guidelines in terms of pH and resistivity that are based on local performance. The FHWA has also published guidelines for aluminum and steel culverts including various protective coatings.

Corrosion and abrasion of corrugated metal culverts can be a serious problem with adverse effects on structural performance. Damage due to corrosion and abrasion is the most common cause for culvert replacement. The inspection should include visual observations of metal corrosion and abrasion. As steel corrodes it expands considerably. Relatively shallow corrosion can produce thick deposits of scale. A geologist's pick-hammer can be used to scrape off heavy deposits of rust and scale permitting better observation of the metal. A hammer can also be used to locate unsound areas of exterior corrosion by striking the culvert wall with the pick end of the hammer. When severe corrosion is present, the pick will deform the wall or break through it. Protective coatings should be examined for abrasion damage, tearing, cracking, and removal. The inspector should document the extent and location of surface deterioration problems.

When heavy corrosion is found by observation or sounding, special inspection methods such as pH testing, electrical resistivity measurement, and obtaining cores from the pipe wall are recommended. A routine program for testing pH and electrical resistivity should be considered since it is relatively easy to perform and provides valuable information.

Durability problems are the most common cause for the replacement of pipe culverts. The condition of the metal in corrugated metal culverts and any coatings, if used, should be considered when assigning a rating to the culvert barrel. Suggested rating guidelines for metal culverts with metallic coatings are shown in exhibit 73. Modification of these guidelines may be required when inspecting culverts with non-metallic coatings. Aluminum culvert barrels may be rated as being in good condition if there is superficial corrosion. Steel culverts rated as in good condition may have superficial rust with no pitting. Perforation of the invert as shown in exhibit 74 would indicate poor condition. Complete deterioration of the invert in all or part of the culvert barrel would indicate a critical condition as shown in exhibit 75. Culverts with deteriorated inverts may function as an arch structurally, but are highly susceptible to failure due to erosion of the bedding.

Rating Value	General Description	Corrugated Steel	Corrugated Aluminum
9	New	Near original condition	Near original condition
8	Good	Superficial rust, no pitting	Superficial corrosion slight pitting
7	Generally Good	Moderate rust, slight pitting	Moderate corrosion no attack of core alloy
6	Fair	Fairly heavy rust, moderate pitting, slight thinning	Significant corrosion minor attack of core alloy
5	Generally Fair	Extensive heavy rust, deep pitting, moderate thinning	Significant corrosion moderate attack of core alloy
4	Marginal	Pronounced thinning (some deflection or penetration when struck with pick hammer)	Extensive corrosion significant attack of core alloy
3	Poor	Extensive heavy rust, deep pitting scattered perforations	Extensive corrosion attack of core alloy scattered perforations
2	Critical	Extensive perforations due to rust	Extensive perforations due to corrosion
1	Critical	Invert completely deteriorated	Invert completely deteriorated
0	Critical	Partial or complete collapse	Partial or complete collapse

Figure 12.4.12 (Exhibit 73) Suggested Rating Criteria for Condition of Corrugated Metal

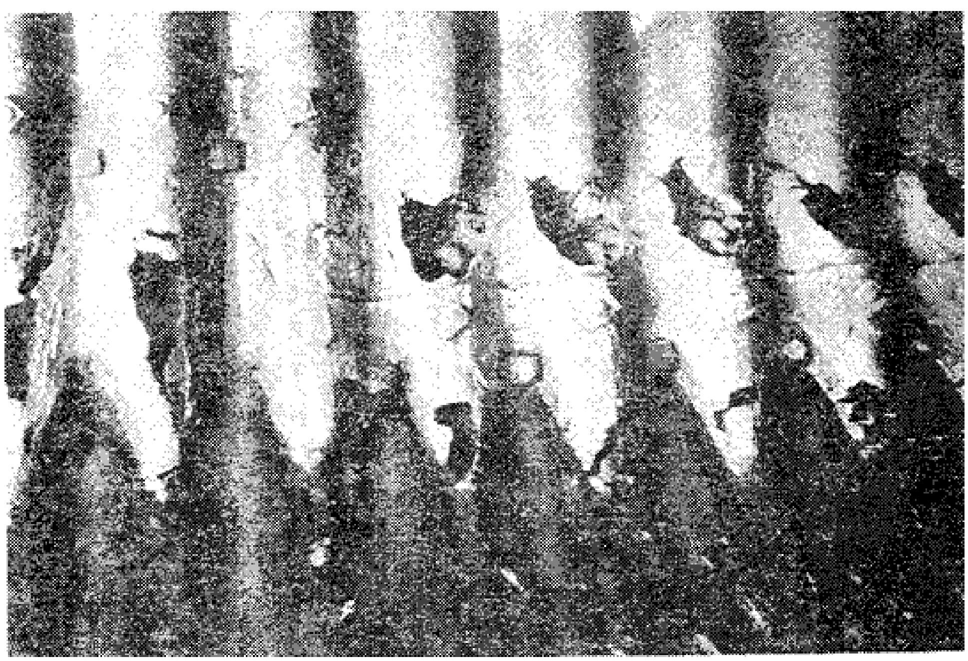


Figure 12.4.13 (Exhibit 74) Perforation of the Invert Due to Corrosion

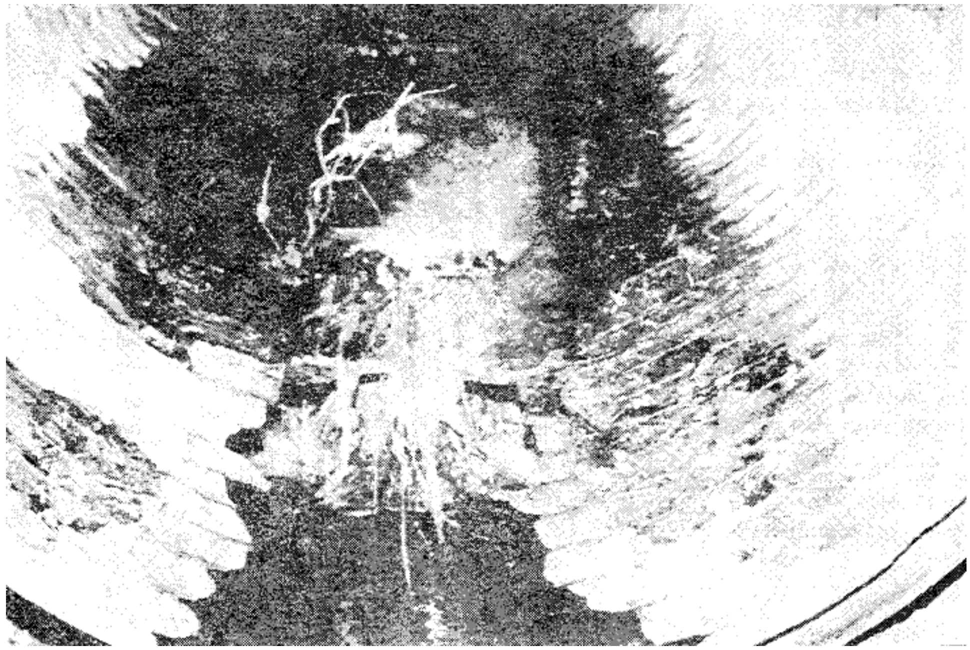


Figure 12.4.14 (Exhibit 75) Invert Deterioration

h. Concrete Footing Defects - Structural plate arches, long-span arches, and box culverts use concrete footings. Metal footings are occasionally used for the arch and box culvert shapes. The metal "superstructure" is dependent upon the footing to transmit the vertical load into the foundation. The structural plate arch is usually bolted in a base channel which is secured in the footing.

The most probable structural defect in the footing is differential settlement. One section of a footing settling more than the rest of the footing can cause wrinkling or other distortion in the arch. Flexible corrugated metal culverts can tolerate some differential settlement but will be damaged by excessive differential settlement. Uniform settlement will not ordinarily affect a metal arch but can affect the clearances in a grade separation structure if the footings settle and the road does not. The significance of differential footing settlement increases as the amount of the difference in settlement increases, the length it is spread over decreases, and the height of the arch decreases. This concept is illustrated in exhibit 76.

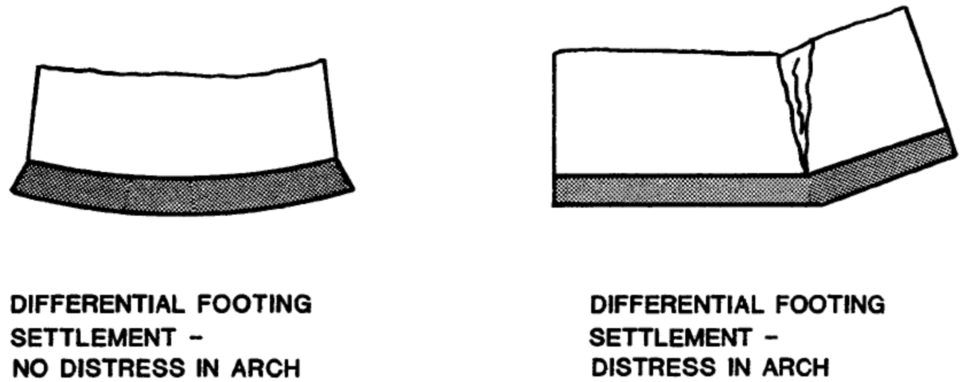


Figure 12.4.15 (Exhibit 76) Differential Footing Settlement

The inspection of footings in structural plate and long-span arches should include a check for differential settlement along the length of a footing. This might show up in severe cracking, spalling, or crushing across the footing at the critical spot. If severe enough, it might be evidenced by compression or stretching of the corrugations in the culvert barrel. Deterioration may occur in concrete and masonry footings which is not related to settlement but is caused by the concrete or mortar. In arches with no invert slab, the inspector should check for erosion and undermining of the footings and look for any indication of rotation of the footing as illustrated in exhibits 77 and 78.

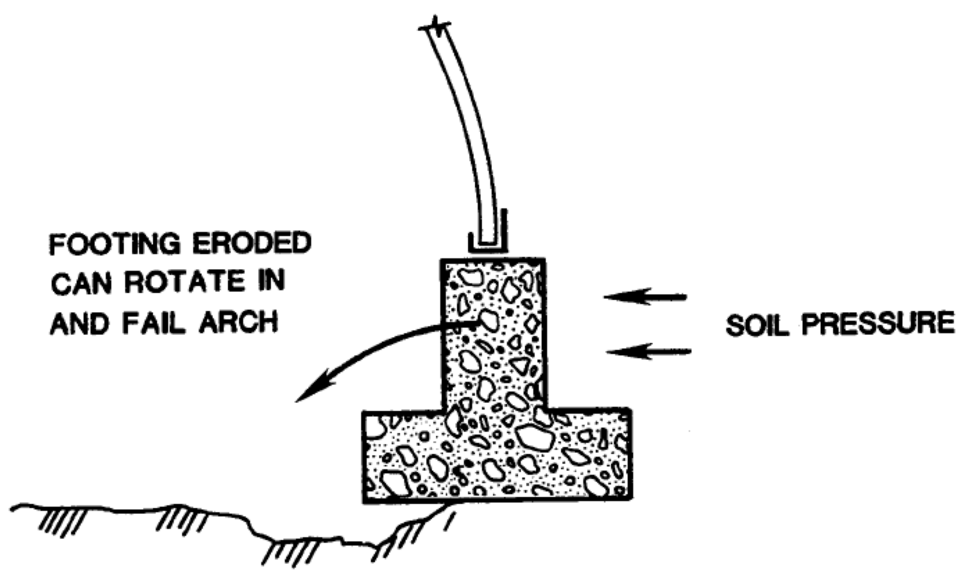


Figure 12.4.16 (Exhibit 77) Footing Rotation due to Undermining

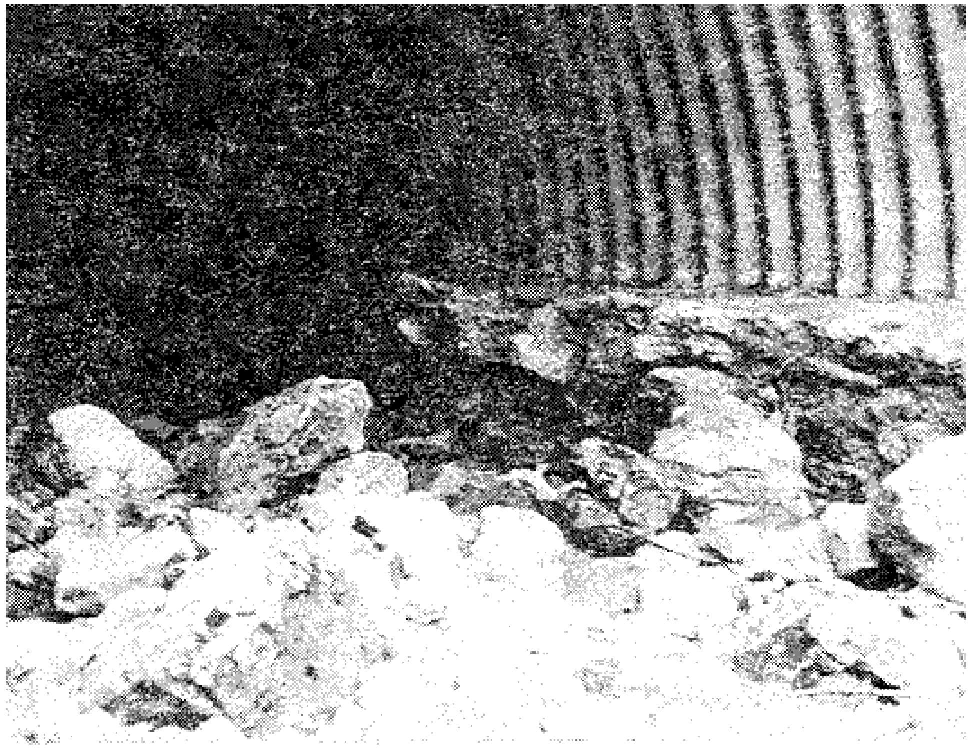


Figure 12.4.17 (Exhibit 78) Erosion of Invert Undermining footing of Arch

Culverts rated in good condition may have minor footing damage. Poor to critical condition would be indicated by severe footing undermining, damage, or rotation, or by differential settlement causing distortion and circumferential kinking in the corrugated metal as shown in exhibit 79.

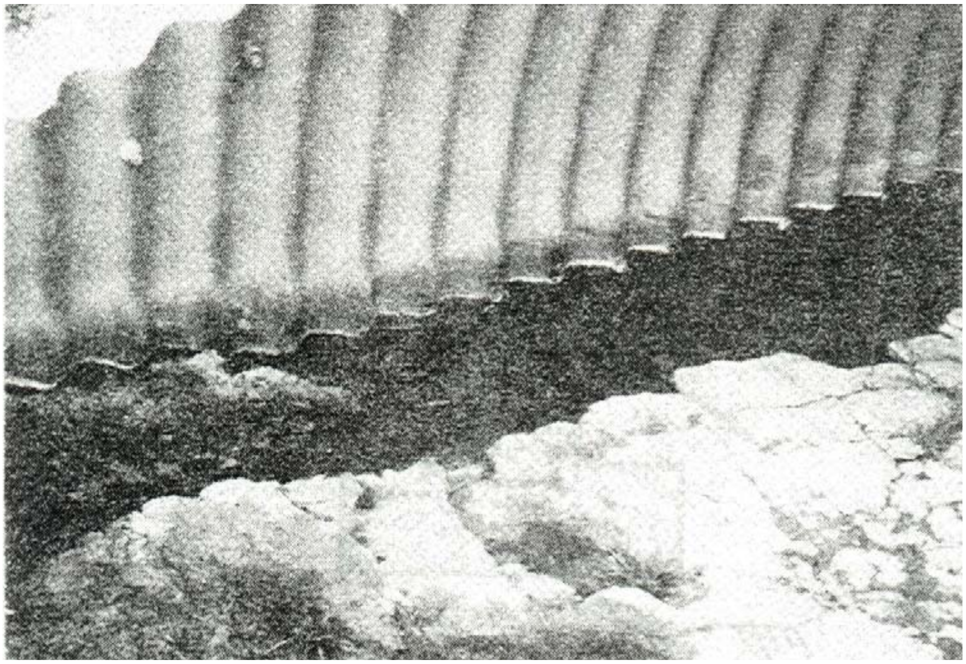


Figure 12.4.18 (Exhibit 79) Erosion Damage to Concrete Invert

i. Defects in Concrete Inverts - Concrete inverts in arches are usually floating slabs used to carry water or traffic. Invert slabs provide protection against erosion and undercutting, and are also used to improve hydraulic efficiency. Concrete inverts are sometimes used in circular, as well as other culvert shapes, to protect the metal from severe abrasive or severe corrosive action. Concrete invert slabs in arches should be checked for undermining and damage such as spalls, open cracks, and missing portions. The significance of damage will depend upon its effect on the footings and corrugated metal.

The following excerpts are from a reproduction of the out-of-print Culvert Inspection Manual (Supplement to Manual 70), July 1986 – Chapter 5, Section 5.

Section 5 - SHAPE INSPECTION OF CORRUGATED METAL CULVERT BARRELS

5-5.0 General

This section deals with shape inspections of common culvert shapes including round and vertical elongated, pipe arches, arches, and box culvert shapes. Specific guidelines for recommended measurements to be taken for each location are provided for each typical culvert shape. Additional measurements are also recommended when field measurements differ from the design dimensions or when significant shape changes are observed. Rating guidelines are also provided for each shape. The guidelines include condition descriptions with shape and barrel defects defined for each rating.

5-5.1 Using the Rating Guidelines

When using the rating guidelines, the inspector should keep the following factors in mind:

a. The inspector should select the lowest rating which best describes either the shape condition or the barrel condition. Structure shape is the most critical factor in flexible culverts, and this should be kept in mind when selecting the rating.

b. The shape criteria described for each numerical rating should be considered as a group rather than as separate criteria for each measurement check listed. Good curvature and the rate of change are critical. Significant changes in shape since the last inspection should be carefully evaluated even if the structure is still in fairly good condition.

c. The guidelines merely offer a starting point for the inspector. The inspector must still use judgment in assigning the appropriate numerical rating. The numerical rating should be related to the actions required. The inspector may wish to refer to Section 4.2 of this manual.

5-5.2 Round and Vertical Elongated Pipe

Round and vertically elongated pipes are expected to deflect vertically during construction resulting in a slightly increased horizontal span. Round pipes are sometimes vertically elongated five percent to compensate for settlement during construction. It is frequently difficult to determine in the field if a pipe was round or elongated when installed. Large round pipes may appear to be elongated if they were subjected to minor flattening of the sides during backfill.

Vehicular underpasses sometimes use 10 percent vertically elongated very large pipe which is susceptible to side flattening during installation. In shallow cover situations, adequate curvature in the sides is the important factor. The soil pressures on the sides may be greater than the weight of the shallow fill over the pipe. The result is a tendency to push the sides inward rather than outward as in deeper buried or round pipes. Side flattening, such as that shown in exhibit 80, can be caused by unstable backfill. A deteriorated invert may have contributed to the problem by reducing the pipe's ability to transmit compressive forces.

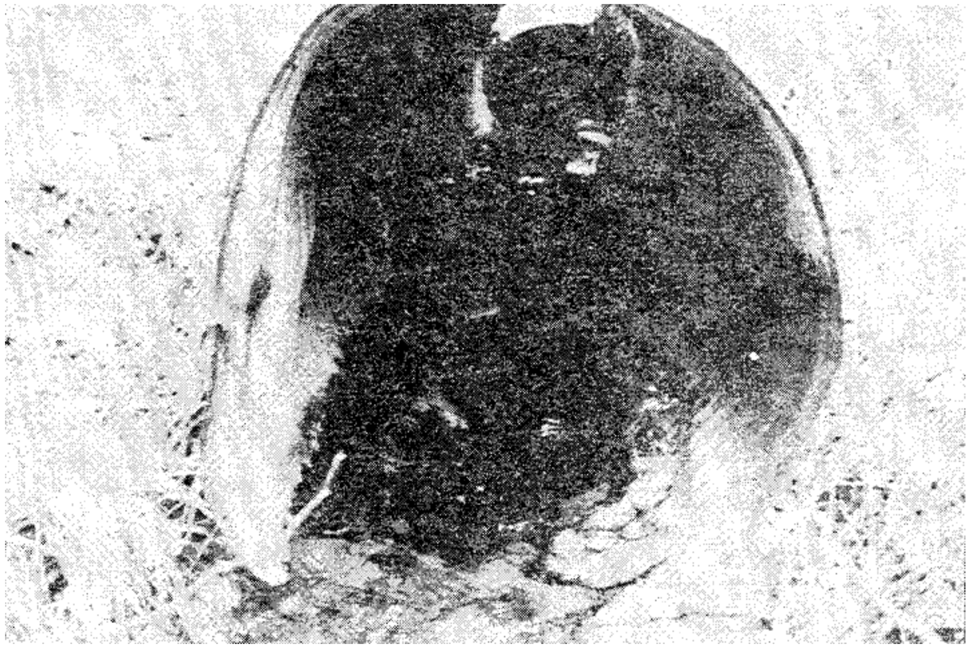


Figure 12.4.19 (Exhibit 80) Excessive Side Deflection

Flattening of the top arc is an indication of possible distress. Flattening of the invert is not as serious. Pipes not installed on shaped bedding will often exhibit minor flattening of the invert arc. However, severe flattening of the bottom arc would indicate possible distress.

The inspector should note the visual appearance of the culvert's shape and measure the horizontal span as shown in exhibit 81. Almost all round or vertical elongated pipe can be directly measured and will not require elevations. Exceptions are large vertical elongated grade separation structures. On such structures, elevations should be obtained similar to those recommended for the long-span pear shape.

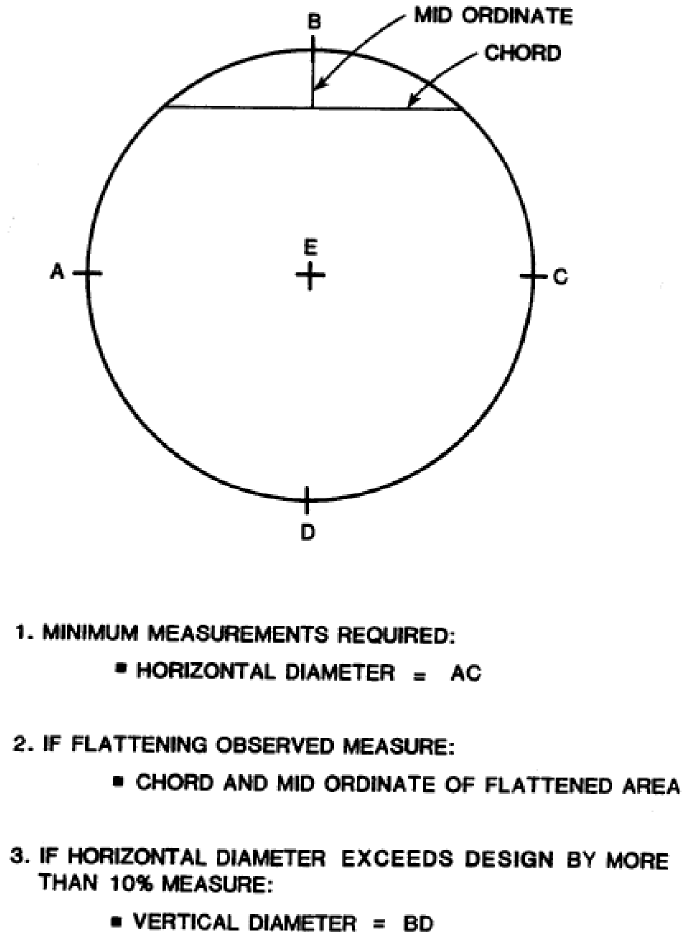


Figure 12.4.20 (Exhibit 81) Shape Inspection Circular and Vertical Elongated Pipe

If the visual appearance or measured horizontal diameter differ significantly from the design specifications, additional measurement, such as vertical diameter, should be taken. Flattened areas should be checked by measuring a chord and the mid ordinate of the chord. The chord length and ordinate measurement should be noted in the report with a description of the location and extent of the flattened area.

Round and vertically elongated pipe with good to fair shape will have a generally good shape appearance. Good shape appearance means that the culvert's shape appears to match the design shape, with smooth, symmetrical curvature and no visible deformations. The horizontal span should be within 10 percent of the design span. Pipe with marginal shape will be indicated by characteristics such as a fair or marginal general shape appearance, distortion in the upper half of the pipe, severe flattening in the lower half of the pipe, or horizontal spans 10 to 15 percent greater than design.

Pipe with poor to critical shape will have a poor shape appearance that does not match the design shape, does not have smooth or symmetrical curvature, and may have obvious deformations. Severe distortion in the upper half of the pipe, a horizontal diameter more than 15 percent to 20 percent greater than the design diameter, or flattening of the crown to an arc with a radius of 20 to 30 feet or more would indicate poor to critical condition. It should be noted that pipes with deflection of less than 15 to 20 percent may be rated as critical based on poor shape appearance. Guidelines for rating round corrugated metal culvert are presented in exhibit 82.

RATING GUIDELINES FOR ROUND OR VERTICAL ELONGATED CORRUGATED METAL PIPE BARRELS

RATING	CONDITION
9	• New condition
8	• Shape: good, smooth curvature in barrel - Horizontal: within 10 percent of design • Seams and Joints: tight, no openings • Metal: - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting
7	• Shape: generally good, top half of pipe smooth but minor flattening of bottom - Horizontal Diameter: within 10 percent of design • Seams or Joints: minor cracking at a few bolt holes, minor joint or seam openings, potential for backfill infiltration • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting
6	• Shape: fair, top half has smooth curvature but bottom half has flattened significantly - Horizontal Diameter: within 10 percent of design • Seams or Joints: minor cracking at bolts is prevalent in one seam in lower half of pipe. Evidence of backfill infiltration through seams or joints • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting
5	• Shape: generally fair, significant distortion at isolated locations in top half and extreme flattening of invert - Horizontal Diameter: 10 percent to 15 percent greater than design • Seams or Joints: moderate cracking at bolt holes along one seam near bottom of pipe, deflection of pipe caused by backfill infiltration through seams or joints • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting
4	• Shape: marginal significant distortion throughout length of pipe, lower third may be kinked - Horizontal Diameter: 10 percent to 15 percent greater than design • Seams or Joints: Moderate cracking at bolt holes on one seam near top of pipe, deflection caused by loss of backfill through open joints • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting
3	• Shape: poor with extreme deflection at isolated locations, flattening of crown, crown radius 20 to 30 feet - Horizontal Diameter: in excess if 15 percent greater than design • Seams: 3 in. long cracks at bolt holes on one seam • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations
2	• Shape: critical, extreme distortion and deflection throughout pipe, flattening of crown, crown radius over 30 feet - Horizontal Diameter: More than 20 percent greater than design • Seams: plate cracked from bolt to bolt on one seam • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust
1	• Shape: partially collapsed with crown in reverse curve • Seams: failed • Road: closed to traffic
0	• Pipe: totally failed • Road: closed to traffic

NOTES:
1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.21 (Exhibit 82) Condition Rating Guidelines

5-5.3 Pipe Arch

The pipe arch is a completely closed structure but is essentially an arch. The load is transmitted to the foundation principally at the corners. The corners are much like footings of an arch. There is relatively little force or pressure on the large radius bottom plate. The principal type of distress in a pipe arch is a result of inadequate soil support at the corners where the pressure is relatively high. The corner may push down or out into the sail while the bottom stays in place. The effect will appear as if the bottom pushed up. This problem is illustrated in exhibits 83 and 84.

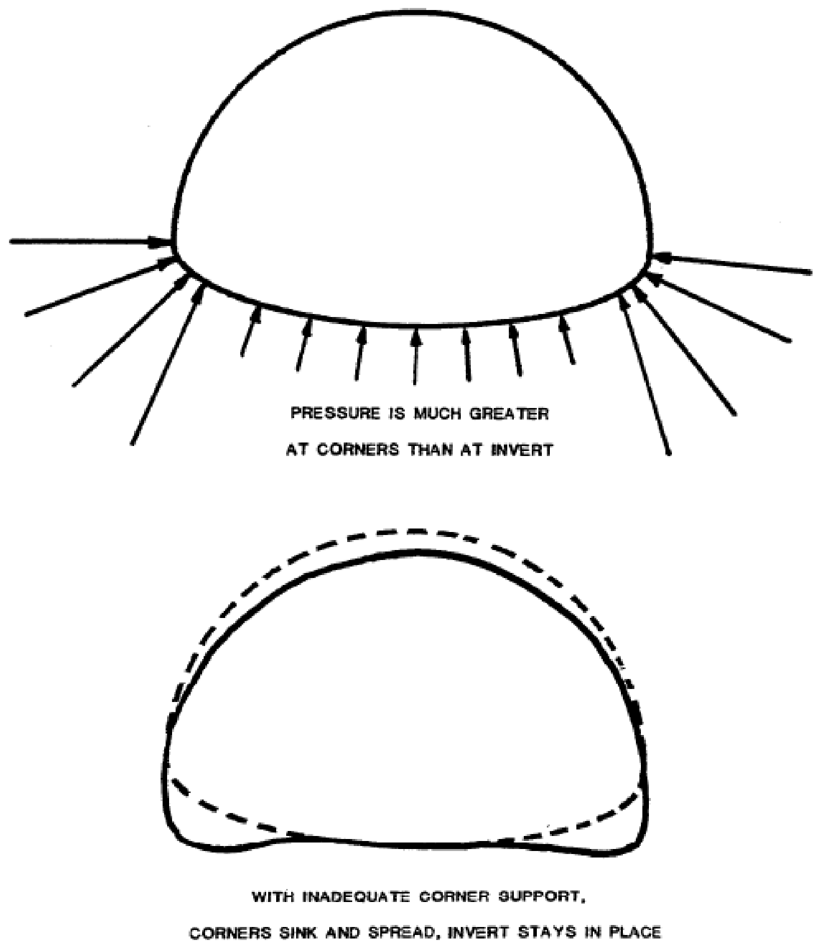


Figure 12.4.22 (Exhibit 83) Bottom Distortion in Pipe Arches

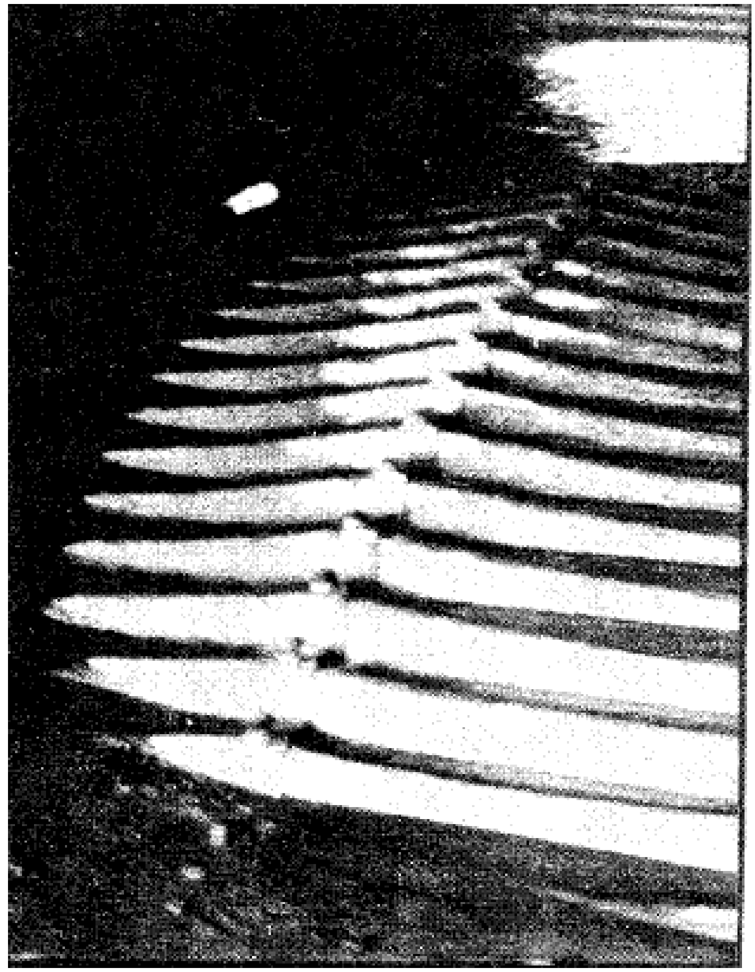
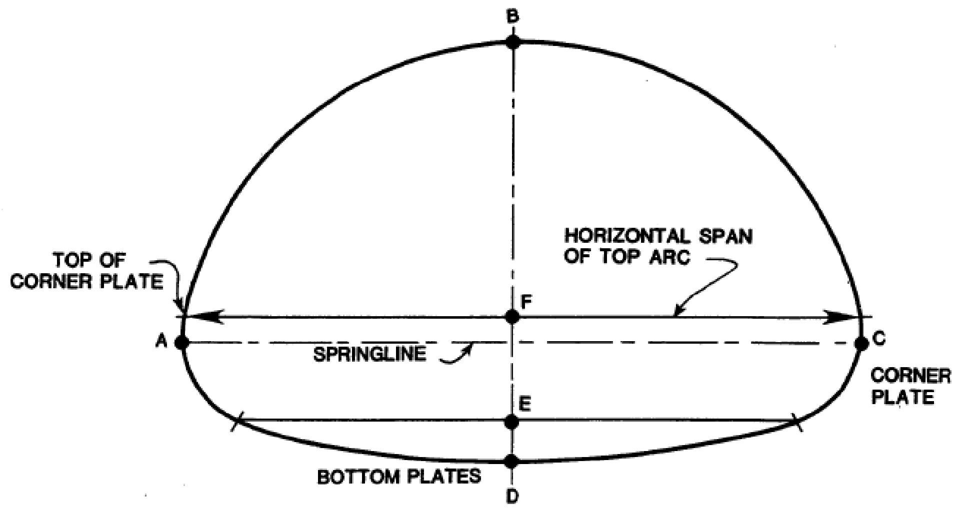


Figure 12.4.23 (Exhibit 84) Bottom and Corners of this Pipe Arch have Settled

The bottom arc should be inspected for signs of flattening and the bottom corners for signs of spreading. The extent and location of bottom flattening and corner spreading should be noted in the inspection report.

Complete reversal of the bottom arc can occur without failure if corner movement into the foundation has stabilized. The top arc of the structure is supporting the load above and its curvature is an important factor. However, if the "footing" corner should fail, the top arc would also fail. The spreading of the corners is therefore very important as it affects the curvature of the top arc.

The inspector should record the visual appearance of the shape and measure both the span and the rise. If the span exceeds the design span by more than 3 percent, the span of the top arc, the mid ordinate of the top arc, and the mid ordinate of the bottom arc should also be measured. Recommended measurements are shown in exhibit 85.



1. MINIMUM REQUIRED MEASUREMENTS – AC, BD
   - SPAN = AC
   - RISE = BD

2. IF AC EXCEEDS DESIGN BY 3% OR MORE MEASURE BF, ED, AND HORIZONTAL SPAN OF TOP ARC

Figure 12.4.24 (Exhibit 85) Shape Inspection Structural Plate Pipe Arch

Pipe arches in fair to good condition will have a symmetrical appearance, smooth curvature in the top of the pipe, and a span less than five percent greater than theoretical. The bottom may be flattened but should still have curvature. Pipe arches in marginal condition will have fair to marginal shape appearance, with distortion in the top half of the pipe, slight reverse curvature in the bottom of the pipe, and a horizontal span five to seven percent greater than theoretical. Pipe in poor to critical condition will have characteristics such as a poor shape appearance, severe deflection or distortion in the top half of the pipe, severe reverse curvature in the bottom of the pipe, flattening of one side, flattening of the crown to an arc with a radius of 6.1 to 9.1 m (20 to 30 feet), or a horizontal span more than seven percent greater than theoretical. Guidelines for rating pipe arches are shown in exhibit 86.

RATING GUIDELINES FOR CORRUGATED METAL PIPE-ARCH BARRELS

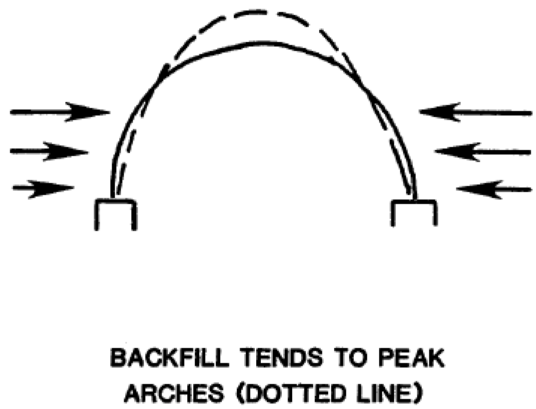
RATING	CONDITION
9	• New condition
8	• Shape: good with smooth curvature - Horizontal Span: less than 3 percent greater than design • Joints or Seams: good condition • Metal: minor construction defects, protective coatings intact - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting
7	• Shape: generally good, smooth curvature in top half, bottom flattened but still curved - Horizontal Span: within 3 to 5 percent greater than design • Joints or Seams: minor cracking at a few bolt holes; minor joint or seam openings, infiltration of backfill possible • Metal: protective coating ineffective - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting
6	• Shape: fair, smooth curvature in top half, bottom flat - Horizontal Span: 5 percent greater than design • Joints or Seams: minor cracking all along one seam; minor joint openings with evidence of infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting
5	• Shape: generally fair, significant distortion in top in one location; bottom has slight reverse curvature in one location - Horizontal Span: within 5 to 7 percent greater than design • Joints and Seams: moderate cracking at bolt holes along a seam in one section, backfill being lost through seam or joint causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting
4	• Shape: marginal, significant distortion all along top of arch, bottom has reverse curve - Horizontal Span: more than 7 percent greater than design • Joints and Seams: moderate cracking all along one seam; backfill infiltration causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting
3	• Shape: poor, extreme deflection in top arch in one section; bottom has reverse curvature throughout - Horizontal Span: more than 7 percent greater than design • Seams: seam cracked 3 in. on each side of bolt holes • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations
2	• Shape: critical, extreme deflection along top of pipe - Horizontal Span: more than 7 percent greater than design • Seams: seam cracked from bolt to bolt down one seam • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust
1	• Shape: structure partially collapsed • Seams: seam failed • Road: closed to traffic
0	• Shape: structure collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.25 (Exhibit 86) Condition Rating Guidelines

5-5.4 Arches.

Arches are fixed on concrete footings, usually below or at the springline. The springline is a line connecting the outermost points on the sides of a culvert. This difference between pipes and arches means that an arch tends to deflect differently during backfill. Backfill forces tend to flatten the arch sides and peak its top because the springline cannot move inward like the wall of a round pipe as shown in exhibit 87. As a result, important shape factors to look for in an arch are flattened sides, peaked crown, and flattened top arc.



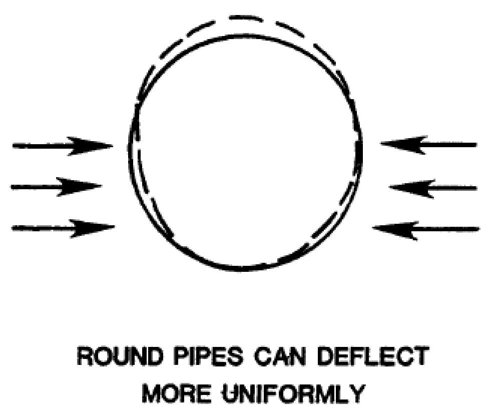


Figure 12.4.26 (Exhibit87) Arch Deflection During Installation

Another important shape factor in arches is symmetrical shape. If the arch was erected with the base channels not square to the centerline, it causes a racking of the cross section. A racked cross-section is one that is not symmetrical about the centerline of the culvert. One side tends to flatten, the other side tends to curve more while the crown moves laterally and possibly upward. If these distortions are not corrected before backfilling the arch, they usually get worse during backfill. Exhibit 88 illustrates racked or peaked arches.

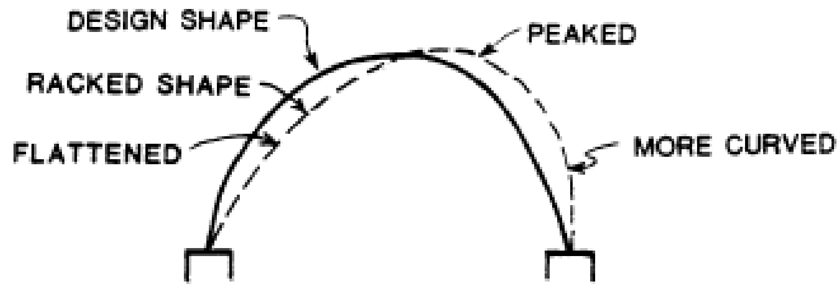
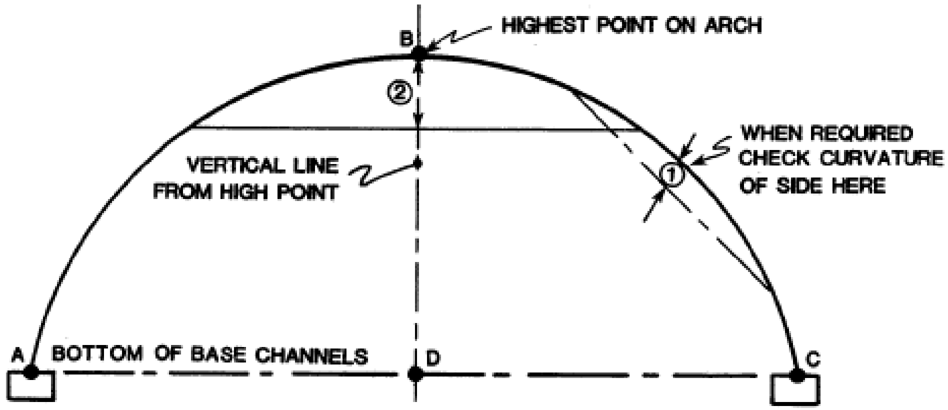


Figure 12.4.27 (Exhibit 88) Racked and Peaked Arch

Visual observation of the shape should involve looking for flattening of the sides, peaking or flattening of the crown, or racking to one side. The measurements to be recorded are illustrated in exhibit 89. Minimum measurements include the vertical distance from the crown to the bottom of the base channels and the horizontal distances from each of the base channels to a vertical line from the highest point on the crown. These horizontal distances should be equal. When they differ by more than 10 inches or 5 percent of the span, whichever is less, racking has occurred and the curvature on the flatter side of the arch should be checked by recording chord and midordinate measurements. Racking can occur when the rise checks with the design rise. When the rise is more than 5 percent less than the design rise, the curvature of the top arc should be checked.



1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AD + DC
   - RISE = BD

2. MINIMUM REQUIRED ELEVATIONS – B

3. IF BD GREATER THAN DESIGN BY 5% OR MORE
   CHECK SIDE CURVATURE

4. IF AD AND DC NOT EQUAL CHECK SIDE CURVATURE ①

5. IF BD LESS THAN DESIGN BY 5% OR MORE
   CHECK TOP CURVATURE ②

Figure 12.4.28 (Exhibit 89) Shape Inspection Structural Plate Arch

Arches in fair to good condition will have the following characteristics: a good shape appearance with smooth and symmetrical curvature, and a rise within three to four percent of theoretical. Marginal condition would be indicated when the arch is significantly non-symmetrical, when arch height is five to seven percent less or greater than theoretical, or when side or top plate flattening has occurred such that the plate radius is 50 to 100 percent greater than theoretical. Arches in poor to critical condition will have a poor shape appearance including significant distortion and deflection, extremely non-symmetrical shape, severe flattening (radius more than 100 percent greater than theoretical) of sides or top plates, or a rise more than eight percent greater or less than the theoretical rise. Guidelines for rating structural plate arches are shown in exhibit 90.

RATING GUIDELINES FOR STRUCTURAL PLATE ARCH BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good, smooth symmetrical curvature • Rise: within ± 3 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to contraction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good with smooth curvature, symmetrical; slight flattening of top or sides in one section • Rise: within 3 to 4 percent of design • Seams: minor cracking at a few bolt holes; minor seam opening, possibility of soil infiltration • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: moderate erosion causing differential settlement and minor cracking in footing
6	• Shape: fair, smooth curvature but non-symetrical; slight flattening of top and sides throughout • Rise: within 4 to 5 percent of design • Seams: minor cracking of bolt holes along one or more seams; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footings: moderate cracking and differential settlement of footing due to extensive erosion
5	• Shape: generally fair, significant distortion and deflection in one section; sides beginning to flattend; non-symetrical • Rise: within 5 to 7 percent of design • Seams: moderate cracking of one seam near footing; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking in footing
4	• Shape: marginal, significant distortion and deflection throughout; sides flattened with radius 100 percent greater than design • Rise: within 7 to 8 percent of design • Seams: major cracking of seam near crown; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due to erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor, extreme distortion and deflection in one section; sides virtually flattened; extremely non-symetrical • Rise: within 8 to 10 percent of design • Seams: cracked 3" to either side of bolts • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut; major cracking and spalling
2	• Shape: critical, extreme deflection, throughout; sides flattened; extremely non-symetrical • Rise: greater than 10 percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; local reverse curve of crown and sides • Seams: failed, backfill pushing in • Road: closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.29 (Exhibit 90) Condition Rating Guidelines

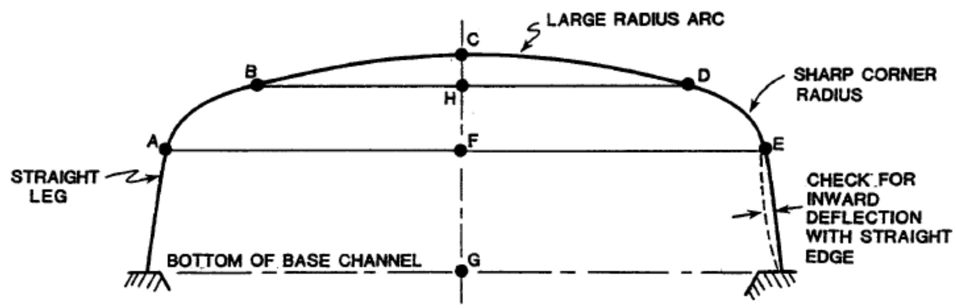
5-5.5 Corrugated Metal Box Culverts.

The box culvert is not like the other flexible buried metal structures. It behaves as a combination of ring compression action and conventional structure action. The sides are straight, not curved and the plates are heavily reinforced and have moment or bending strength that is quite significant in relation to the loads carried.

The key shape factor in a box culvert is the top arc. The design geometry is clearly very “flat” to begin with and therefore cannot be allowed to deflect much. The span at the top is also important and cannot be allowed to increase much.

The side plates often deflect slightly inward or outward. Generally an inward deflection would be the more critical as an outward movement would be restrained by soil.

Shape factors to be checked visually include flattening of top arc, outward movement of sides, or inward deflection of the sides. The inspector should note the visual appearance of the shape and should measure and record the rise and the horizontal span at the top of the straight legs as shown in exhibit 91. If the rise is more or less than 1 ½ percent of the design rise, the curvature of the large top radius should be checked.



1. MINIMUM REQUIRED MEASUREMENTS
   - RISE = CG
   - SPAN = AE
2. IF NOT POSSIBLE TO MEASURE CG, MEASURE BD AND CH
3. IF CG DIFFERS BY MORE THAN 1½% OF DESIGN OR AE DIFFERS BY MORE THAN ±3% OF DESIGN MEASURE
   - CHORD OF TOP ARC = BD
   - MIDDLE ORDINATE OF TOP ARC = CH

Figure 12.4.30 (Exhibit 91) Shape Inspection Structural Plate Box Culverts

The radius points are not necessarily located at the longitudinal seams. Many box culverts use double radius plates and the points where the radius changes must be estimated by the inspector or can be determined from the manufacturer’s literature. These points can still be referenced to the bolt pattern to describe exactly where they are. Since these are all low structures, the spots should also be marked and painted for convenient repeat inspection.

Box culverts in fair to good condition will appear to be symmetrical with smooth curves, slight or no deflection of the straight legs, a horizontal span length within five percent of the design span and the middle ordinate of the tops are within ten percent of the design. Culverts in marginal condition may appear to be non-symmetrical, have noticeable deflection in the straight legs, have spans that differ from design by five percent, or have a middle ordinate of the top arc that differ from design by 20 to 30 percent. Poor to critical conditions exist when the culvert shape appears poor, the culvert has severe deflections of the straight legs, a horizontal span that differs from design by more than five percent, or a middle ordinate of the top arc that differs from the theoretical by more than 40 to 50 percent. Guidelines for rating structural plate box culverts are shown in exhibit 92.

RATING GUIDELINES FOR CORRUGATED METAL BOX CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design • Sides: straight leg very slightly deflected inward or outward and curvature smooth • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design • Sides: straight leg slightly deflected inward or moderately deflected outward, curvature smooth • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design • Sides: straight leg moderately deflected inward or extremely deflected outward, curvature smooth • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Sides: straight leg bowed inward significantly or extremely bowed outward for distance of less than 1/4 span length • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 20 to 30 percent of design - Horizontal Span: more than + or - 5 percent of design - Sides: straight leg bowed inward significantly or extremely bowed outward for distance between 1/4 and 1/2 span length, curvature irregular • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 30 to 40 percent less than design - Horizontal Span: more than + or - 6 percent of design Sides: straight leg extremely bowed inward for distance less than 1/2 span length or leg bowed outward severely causing bulges in metal • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 40 percent less than design - Horizontal Span: more then + or - 8 percent of design - Sides: straight leg extremely bowed inward for a distance of 1/2 to 1 span length, or leg bowed outward severely causing bulges or kinking in metal • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.31 (Exhibit 92) Condition Rating Guidelines

The following excerpts are from a reproduction of the out-of-print Culvert Inspection Manual (Supplement to Manual 70), July 1986 – Chapter 5, Section 6.

Section 6. CORRUGATED METAL LONG-SPAN CULVERTS

5-6.0 General.

This section describes procedures for conducting shape inspections of long-span structures. The long-span structures addressed include four typical shapes: low profile arch, horizontal ellipse, high profile arch, and pear. These shapes are illustrated in exhibit 93. The evaluation of shape characteristics of long-spans will vary somewhat depending upon the typical shape being inspected. However, the top or crown sections of all long-span structures have very similar geometry. The crown sections on all long-span structures can be inspected using the same criteria. This section therefore includes separate discussions on the crown section and on each of the typical long-span shapes. Guidelines are also provided for rating the condition of each shape in terms of shape characteristics and barrel defects. The procedures for using the rating guidelines are the same as those described in section 5-5.1.

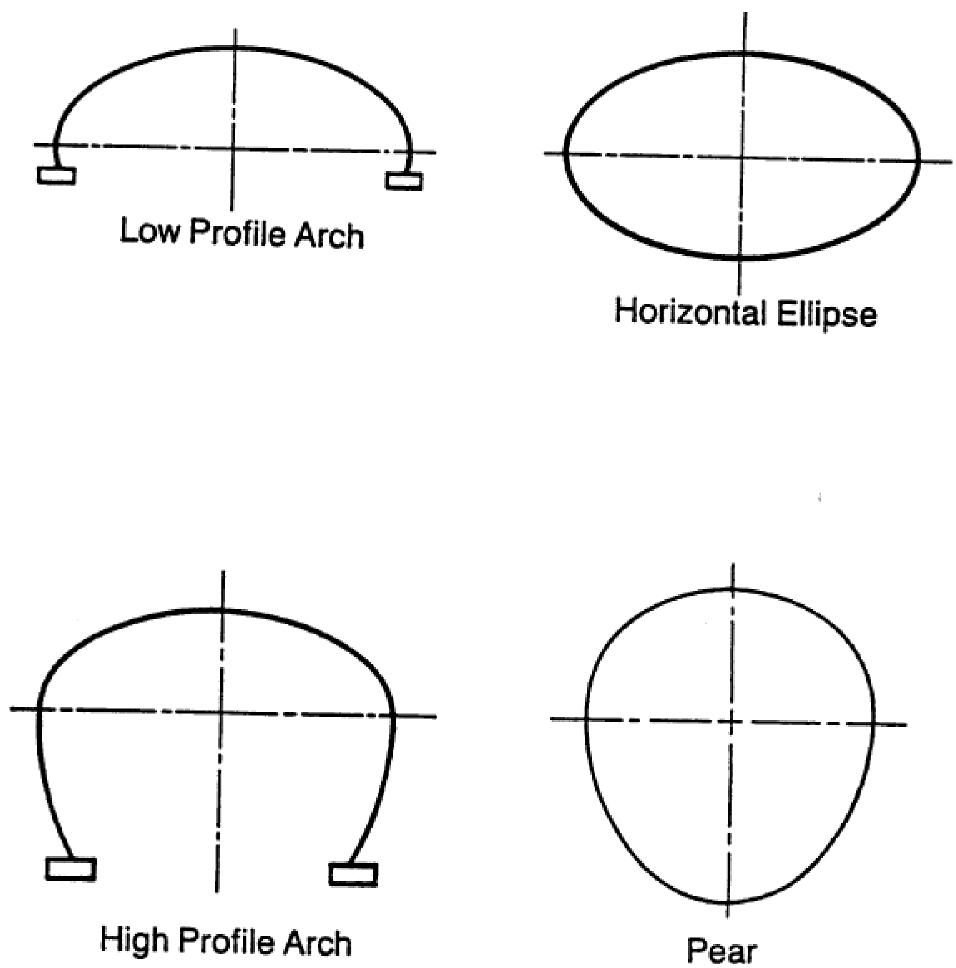
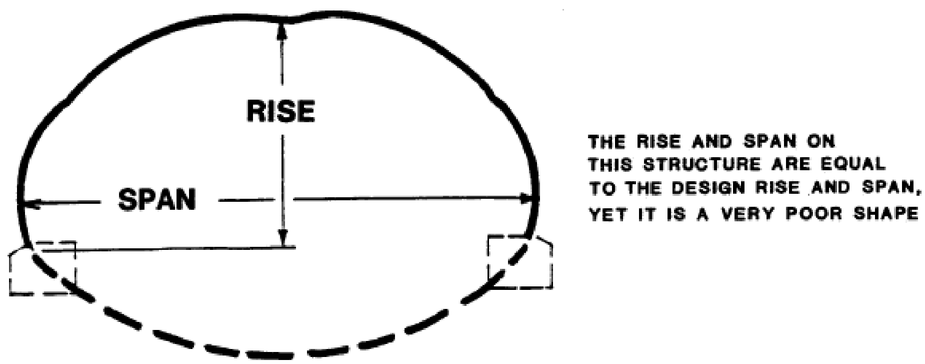


Figure 12.4.32 (Exhibit 93) Typical Long-Span Shapes

Shape inspections of long-span structures will generally consist of 1) visual observations of shape characteristics such as smooth or distorted curvature and symmetrical or non-symmetrical shape, 2) measurements of key dimensions, and 3) elevations of key points. Additional measurements may be necessary if measurements or observed shape differ significantly from design.

The visual observations are extremely important to evaluate the shape of the total cross section. Simple measurements such as rise and span do not describe curvature, yet adequate curvature is essential, as shown in exhibit 94. However, measurements and elevations are also needed to document the current shape so that the rate change, if any, can be monitored.



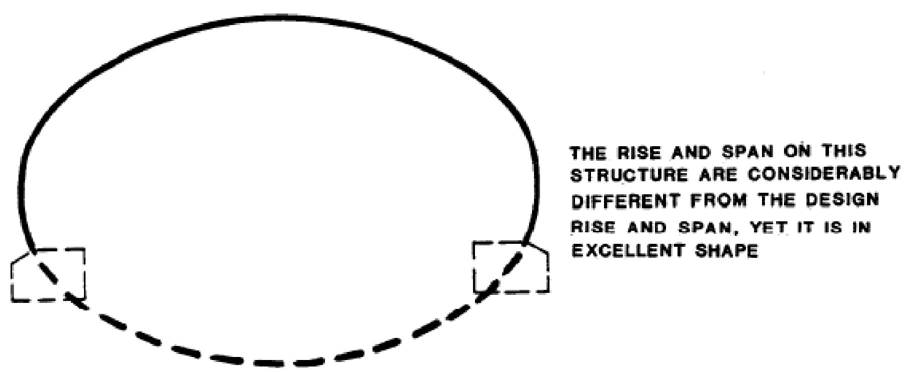


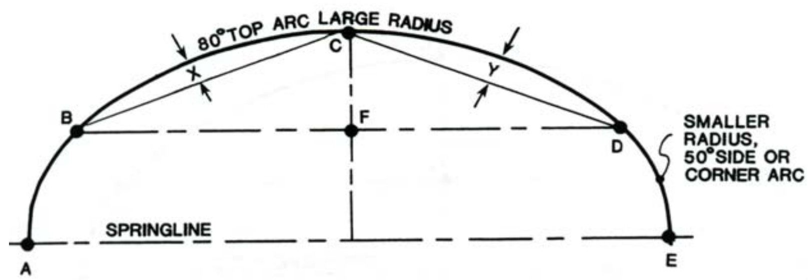
Figure 12.4.33 (Exhibit 94) Erosion Damage to Concrete Invert

Many long-spans will be too large to allow simple direct measuring. Vertical heights may be as large as 6.1 to 9.1 m (20 to 30 feet) and horizontal spans may be large and as high as 3.7 to 4.6 m (12 to 15 feet) above inverts. Culverts may have flowing water obscuring the invert and any reference points there. It is, therefore, in general desirable to have instrument survey points, which can be quickly checked for elevation. When direct measuring is practical a 7.6 m (25 foot) telescoping extension rod can be used for measuring. Such rods can also serve as level rods for taking elevations.

5-6.1 Long-Span Crown Section - Shape Inspection.

As previously mentioned, the section above the springline is essentially the same for most long-span shapes. With the exception of pear shapes, the standard top geometry uses a large radius top arc of approximately 80 degrees with a radius of 4.6 to 7.6 m (15 to 25 feet). The adjacent corner or side plates are from one-half to one-fifth the top arc radius. The most important part of a long-span shape is the standard top arch geometry. Adequate curvature of the large radius top arc is critical. Inspection of the crown section should consist of a visual inspection of the general shape for smooth curvature (no distortion, flattening, peaks, or cusps) and symmetrical shape (no racking).

An inspection should also include key measurements such as the middle ordinate of the top arc. Recommended measurements and elevations are shown in exhibit 95.



1. MINIMUM REQUIRED ELEVATIONS – B, C, D

   MINIMUM REQUIRED MEASUREMENTS –
   - TOP SPAN = AE

   CALCULATE CF = $\text{ELEV C} - \dfrac{\text{ELEV B} + \text{ELEV D}}{2}$

2. IF CF IS GREATER THAN OR LESS THAN DESIGN BY 10% MEASURE:
   - TOP ARC CHORD = BD

3. IF BD DIFFERS BY MORE THAN 3% FROM DESIGN MEASURE FOR EACH HALF OF TOP ARC
   - HALF TOP ARC MID ORDINATES = X & Y

Note: These measurements and elevations should be obtained on all long span inspections (see exhibits 96, 98, 100 and 103).

Figure 12.4.34 (Exhibit 95) Shape Inspection Crown Section of Long Span Structures

The initial inspection should establish elevations for the radius points and the top of the crown. From these elevations the middle ordinate for the top arc can be calculated. If the actual middle ordinate is 10 percent more or less than the theoretical design mid-ordinate the horizontal span for the top arc should also be measured. For standard 80 degree arcs the theoretical middle ordinate is equal to 0.234 times the theoretical radius of the top arc. This span is not easy to measure on many long-span structures and need not be measured if the top arc mid-ordinate is within 10 percent of theoretical. Even if it is convenient and practical to direct measure the vertical heights of the points on the top arc from the bottom of the structure, it is wise to also establish their elevations from a reliable benchmark. Bottom reference points can be wiped out by erosion, covered with debris, or covered by water. When direct vertical measuring is practical, the shape may be checked on subsequent inspections with direct measurement. However, it is still important to establish elevations in case bottom reference points are lost or inaccessible.

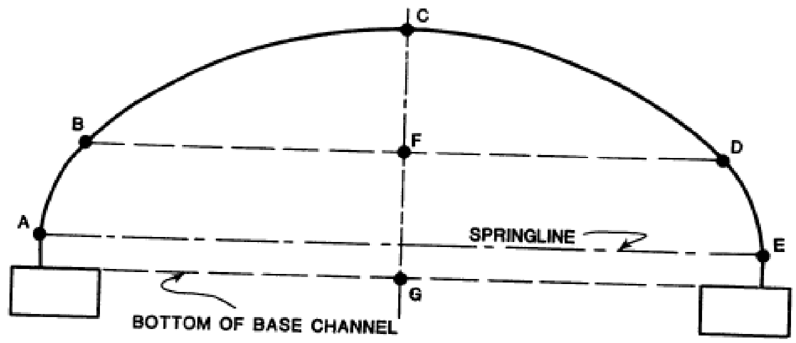
Crown sections in good condition will have a shape appearance that is good, with smooth and symmetrical curvature. The actual middle ordinate should be within 10 percent of the theoretical, and the horizontal span (if measured) should be within five percent of theoretical. Crown sections in fair condition will have a fair to good shape appearance, smooth curvature but possibly slightly non-symmetrical. Middle ordinates of the top arc may be within 11 to 15 percent of theoretical and the horizontal span may differ by more than 5 percent of theoretical.

Crown sections in marginal condition will have measurements similar to those described for fair shape. However, the shape appearance will be only fair to marginal with noticeable distortion, deflection, or non-symmetrical curvature. When the curvature is noticeably distorted or non-symmetrical, the sides should be checked for flattening by measuring the middle ordinates of the halves of the top arc. Crown sections with marginal shape may have middle ordinates for top half arcs that are 30 to 50 percent less than theoretical.

Crown sections in poor to critical condition will have a poor to critical shape appearance with severe distortion or deflection. The middle ordinate of the top arc may be as much as 20 percent less than theoretical, while middle ordinates of the top arc halves may be 50 to 70 percent less than theoretical.

5-6.2 Low Profile Long-Span Arch - Shape Inspection.

The low profile arch is essentially the same as the crown section except that the sides are carried about 10 degrees below the springline to the footing. These structures are low and can be measured more easily than other long-span shapes. Recommended measurements and elevations are shown in exhibit 96. Rating guidelines are listed in exhibit 97.



AE = SPAN, CG = RISE OR HEIGHT

1. MINIMUM REQUIRED MEASUREMENTS -
   - SPAN = AE
   - TOP ARC CHORD = BD
   - RISE = CG

2. MINIMUM REQUIRED ELEVATIONS B, C, D
3. CALCULATE CF FROM ELEVATIONS

$$CF = ELEV.\ C - \frac{ELEV.\ B + ELEV.\ D}{2}$$

Note: Use with exhibit 95, crown inspection.

Figure 12.4.35 (Exhibit 90) Shape Inspection Low Profile Long Span Arch

RATING GUIDELINES FOR LOW PROFILE ARCH LONG-SPAN CULVERT BARREL	
RATING	**CONDITION**
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosin, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists. • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core allow - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy, - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.36 (Exhibit 97) Condition Rating Guidelines

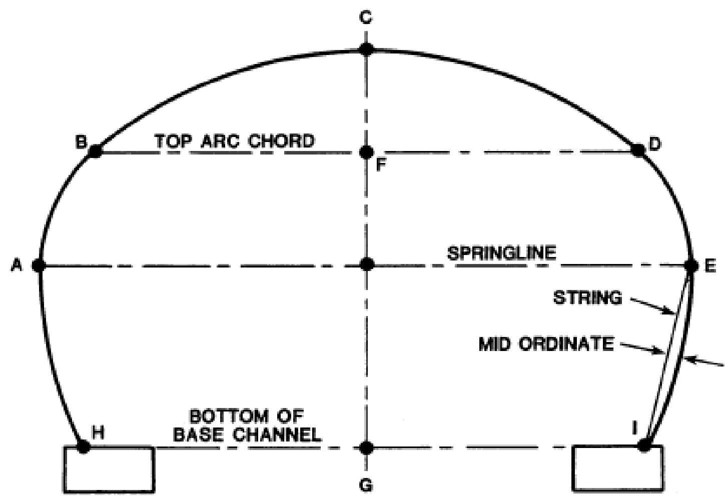
Because arches are fixed on concrete footings, backfill pressures will try to flatten the sides and peak the top. Another important shape factor is symmetry. If the base channels are not square to the centerline of the structure racking may occur during erection. In racked structures, the crown moves laterally and the curvature in one side becomes flatter while the curvature in the other side increases. Backfill pressures may cause this condition to worsen.

5-6.3 High Profile Long-Span Arch – Shape Inspection.

High profile arches have a standard crown section geometry but have high large radius side walls below the springline. Curvature in these side plates is important. In shallow fills or minimum covers, the lateral soil pressures may approach or exceed the loads over the culvert. Excessive lateral forces could cause the sidewall to flatten or buckle inward.

Inspectors should visually inspect high profile arches for flattening of the side plates. Additionally, high profile arches have the same tendencies as regular arches for peaking and racking, so inspectors must also look for peaked top arcs and non-symmetrical or racked arches.

Recommended measurements and elevations are shown in exhibit 98. The shape of the crown section is the most important shape factor. It can be measured and evaluated using the same criteria as that described for the standard crown section. If flattening is observed in the high sidewall the curvature of the sides should be checked by measuring the middle ordinate of the side walls. If the sidewall middle ordinate is no more than 50 to 70 percent less than the theoretical middle ordinate and no other shape problems are found the arch's shape may be considered fair. When the middle ordinate approaches 75 to 80 percent less than theoretical, the shape should be considered marginal. If the middle ordinate is more than 80 to 90 percent less than theoretical the shape should be considered poor to critical. Rating guidelines are provided in exhibit 99.



AE = SPAN, CG = RISE

1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS – B, C, D, H, I

3. CALCULATE CF FROM ELEVATIONS

Note: Use with exhibit 95, crown inspection.

Figure 12.4.37 (Exhibit 98) Shape Inspection High Profile Long-Span Arch

RATING GUIDELINES FOR HIGH PROFILE ARCH LONG-SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Side Plates: smooth curvature • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Side Plates: side flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 35 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 25 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 20 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Side Plates: side flattened, mid-ordinate less than 12 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Side Plates: side flattened, mid-ordinate less than10percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved - Side Plates: side flat or reversed curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.38 (Exhibit 99) Condition Rating Guidelines

5-6.4 Pear Shape Long-Span – Shape Inspection.

The crown section of the pear shape differs from the standard top arch in that smaller radius corner arcs stop short of the horizontal springline. The large radius sides extend above the plane of the horizontal span. In checking curvature of the sides, the entire arc should be checked. Side flattening, particularly in shallow fills, is the most critical shape factor.

The pear shape behaves similarly to the high profile arch. It is essentially a high profile with a metal bottom instead of concrete footings. Pears may be inspected using the criteria for a high profile arch. The recommended measurements and elevations are shown in exhibit 100. Rating guidelines are provided in exhibit 101.

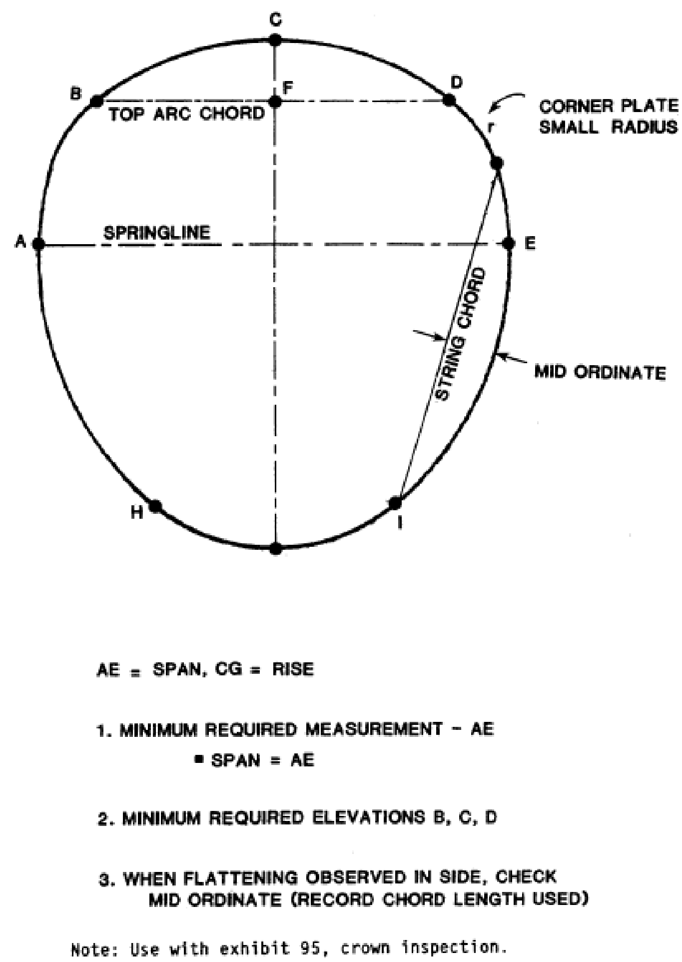


Figure 12.4.39 (Exhibit 100) Shape Inspection Long Span Pear-Shape

RATING GUIDELINES FOR PEAR SHAPED LONG-SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Side Plates: smooth curvature • Seams: properly made and tight • Metal: minor defects and damage due to construction; superficial corrosion with no pitting - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Side Plates: side flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 35 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 25 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: corroded locally - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 20 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of alloy - Steel: extensive heavy rust, deep pitting
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Side Plates: side flattened, mid-ordinate less than 12 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Side Plates: side flattened, mid-ordinate less than10percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved - Side Plates: side flat or reversed curved - Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.40 (Exhibit 101) Condition Rating Guidelines

5-6.5 Horizontal Ellipse – Shape Inspections.

For horizontal ellipses the most important shape factor is adequate curvature in the crown section. The crown section uses the standard long-span crown geometry. The sides and bottom behave similar to the corners and bottom of pipe arches. The invert has relatively minor pressure when compared with the sides, which may have several times the bearing pressure of the invert. As a result the corners and sides have the tendency to push down into the soil while the bottom does not move. The effect is as if the bottom pushed up. Inspectors should look for indications of bottom flattening and differential settlement between the side and bottom sections, as illustrated in exhibit 102.

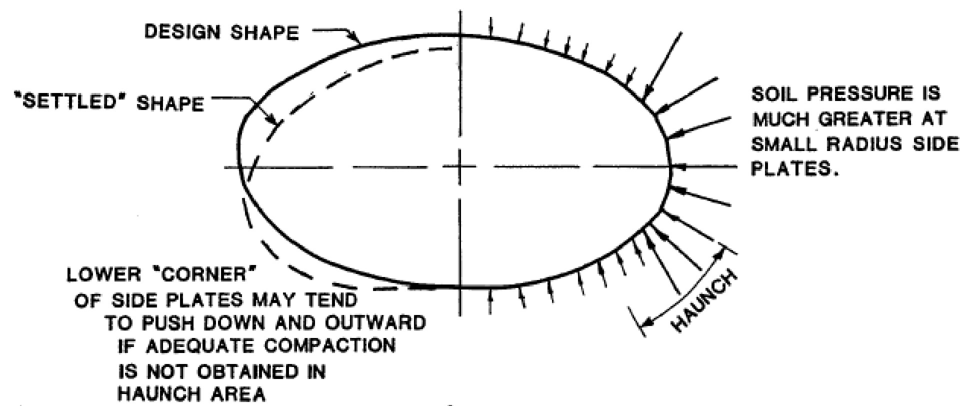
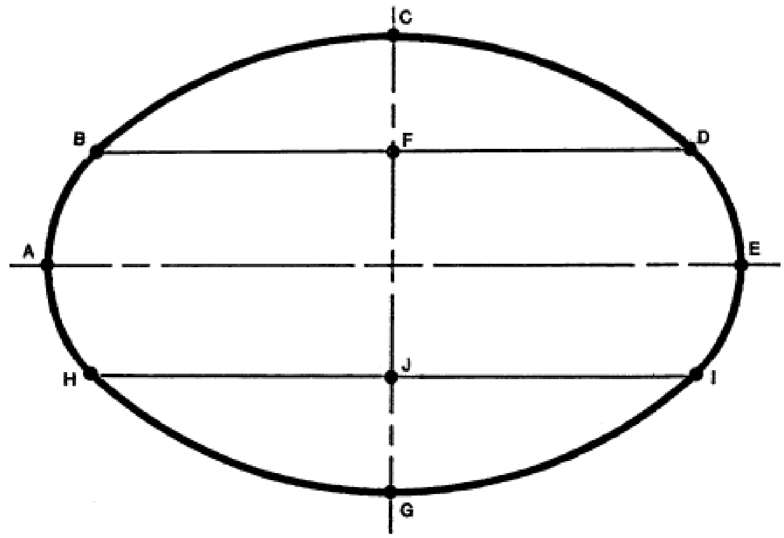


Figure 12.4.41 (Exhibit 102) Potential for Differential Settlement in Horizontal Ellipse

The recommended measurements and evaluations for a shape inspection of horizontal ellipse are shown in exhibit 103. The measurements are essentially the same as those recommended for a standard crown section. Shape evaluation of an ellipse is also essentially the same as the evaluation of a standard crown section except that the curvature of the bottom should also be evaluated. Marginal shape would be indicated when the bottom is flat in the center and corners are beginning to deflect downward or outward. Critical shape conditions would be indicated by reverse curvature in the bottom arc. Guidelines for rating horizontal ellipse shape culverts are provided in exhibit 104.



1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS – B, C, D, G (IF POSSIBLE)

3. WHEN BOTTOM FLATTENING IS OBSERVED, CHECK CURVATURE, MEASURE
   - BOTTOM ARC CHORD = HI
   - BOTTOM ARC MIDDLE ORDINATE = JG

Note: Use with exhibit 95, crown inspection.

Figure 12.4.42 (Exhibit 103) Shape Inspection Long-Span Horizontal Ellipse

RATING GUIDELINES FOR HORIZONTAL ELLIPSE LONG SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Bottom Arc: smooth curvature, mid-ordinate within 50 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Bottom Arc: bottom flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom flattened and irregular, mid-ordinate less than 50 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom virtually flat over center half of arc • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom virtually flat over center half of arc and deflected down at corners • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Bottom Arc: bottom reverse curved in center • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Bottom Arc: bottom reversed curved in center and bulged out at sides • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Figure 12.4.43 (Exhibit 104) Condition Rating Guidelines

12.4.7 Evaluation

State and federal rating guidelines systems have been developed in order to aid in the inspection of flexible culverts. The two major rating guidelines systems currently in use include the National Bridge Inspection Standards (NBIS) rating and the Element level inspection Bridge Management System (BMS).

Application of the NBIS Rating Guidelines

Using NBIS rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the culvert (Item 62). This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. Rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2 for general descriptive codes and Topics 12.4.6 through 12.4.8 for specific codes for the various flexible culverts. The rating code is intended to be an overall evaluation of the culvert. Integral wingwalls to the first construction or expansion joint shall be included in the evaluation. It is also important to note that Items 58-Deck, 59-Superstructure, and 60-Substructure shall be coded “N” for all culverts.

The previous inspection data should be used along with current inspection findings to determine the correct rating.

Application of Condition State Assessment (Element Level Inspection)

A narrative description with quantities is required in the first part of the inspection. Condition state summaries are then developed for the culvert. The information from the narrative and condition state summaries are then used to complete the element level condition report showing quantities at the correct rating value. There are no Element Level Smart Flags specific to culverts.

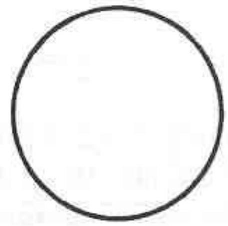
In an element level condition state assessment of a flexible culvert, the AASHTO CoRe element is:

Element No.	Description
240	Unpainted Steel Culvert
243	Culvert: Other

“Culvert: Other” includes masonry, aluminum and combination of other materials. The unit quantity for the culvert is meters or feet and the total length along the barrel must be placed in one of the four available condition states. Condition State 1 is the best possible rating. See Topic 4.6 for condition state descriptions.

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

ROUND



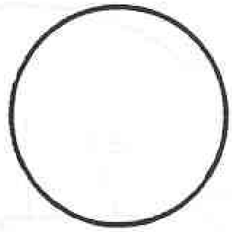
Handling Weight of Corrugated Steel Pipe (2⅔ × ½ in.)
Estimated Average Weights—Not for Specification Use*

Inside Diameter, in.	Specified Thickness, in.	Approximate Pounds per Lineal Ft**			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
12	0.052	8	10	13	
	0.064	10	12	15	
	0.079	12	14	17	
15	0.052	10	12	15	
	0.064	12	15	18	
	0.079	15	18	21	
18	0.052	12	14	17	
	0.064	15	19	22	
	0.079	18	22	25	
21	0.052	14	16	19	
	0.064	17	21	26	
	0.079	21	25	30	
24	0.052	15	17	20	
	0.064	19	24	30	45
	0.079	24	29	35	50
30	0.052	20	22	25	
	0.064	24	30	36	55
	0.079	30	36	42	60
36	0.052	24	26	29	
	0.064	29	36	44	65
	0.079	36	43	51	75
42	0.052	28	30	33	
	0.054	34	42	51	
	0.079	42	50	59	85
48	0.052	31	33	36	
	0.064	38	48	57	
	0.079	48	58	67	95
54	0.064	44	55	66	95
	0.079	54	65	76	105
60	0.079	60	71	85	
	0.109	81	92	106	140
66	0.109	89	101	117	160
	0.138	113	125	141	180
72	0.109	98	112	129	170
	0.138	123	137	154	210
78	0.109	105	121	138	200
	0.138	133	149	166	230
84	0.109	113	133	155	225
	0.138	144	161	179	240
90	0.109	121	145	167	
	0.138	154	172	192	
	0.168	186	204	224	
96	0.138	164	191	217	
	0.168	198	217	239	

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute)

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

ROUND

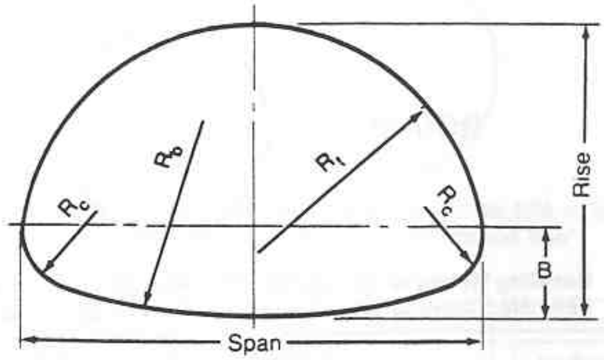


Handling Weight of Corrugated Steel Pipe (3 × 1 in. or 5 × 1 in.)***
Estimated Average Weights—Not for Specification Use

Inside Diameter, in.	Specified Thickness, in.	Approximate Pounds per Lineal Ft**			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
54	0.064	50	66	84	138
	0.079	61	77	95	149
60	0.064	55	73	93	153
	0.079	67	86	105	165
66	0.064	60	80	102	168
	0.079	74	94	116	181
72	0.064	66	88	111	183
	0.079	81	102	126	197
78	0.064	71	95	121	198
	0.079	87	111	137	214
84	0.064	77	102	130	213
	0.079	94	119	147	230
90	0.064	82	109	140	228
	0.079	100	127	158	246
96	0.064	87	116	149	242
	0.079	107	136	169	262
102	0.064	93	124	158	258
	0.079	114	145	179	279
108	0.064	98	131	166	273
	0.079	120	153	188	295
114	0.064	104	139	176	289
	0.079	127	162	199	312
120	0.064	109	146	183	296
	0.079	134	171	210	329
	0.109	183	220	259	378
126	0.079	141	179	220	346
	0.109	195	233	274	400
132	0.079	148	188	231	363
	0.109	204	244	287	419
138	0.079	154	196	241	379
	0.109	213	255	300	438
144	0.109	223	267	314	458
	0.138	282	326	373	517

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Sizes and Layout Details—CSP Pipe Arches
2⅔ × ½ in. Corrugation

Equiv. Diameter, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions B in.	Layout Dimensions R_c in.	Layout Dimensions R_t in.	Layout Dimensions R_b in.
15	17	13	1.1	4⅛	3½	8⅝	25⅝
18	21	15	1.6	4⅞	4⅛	10¾	33⅛
21	24	18	2.2	5⅝	4⅞	11⅞	34⅝
24	28	20	2.9	6½	5½	14	42¼
30	35	24	4.5	8⅛	6⅞	17⅞	55⅛
36	42	29	6.5	9¾	8¼	21½	66⅛
42	49	33	8.9	11⅜	9⅝	25⅛	77¼
48	57	38	11.6	13	11	28⅝	88¼
54	64	43	14.7	14⅝	12⅜	32¼	99¼
60	71	47	18.1	16¼	13¾	35¾	110¼
66	77	52	21.9	17⅞	15⅛	39⅜	121¼
72	83	57	26.0	19½	16½	43	132¼

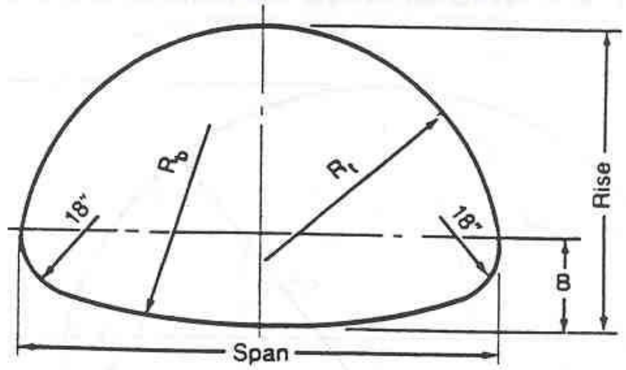
Dimensions shown not for specification purposes, subject to manufacturing tolerances.

Sizes and Layout Details—CSP Pipe-Arches
3 × 1 in. Corrugation

Equiv. Diameter, in.	Size, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions B in.	Layout Dimensions R_c in.	Layout Dimensions R_t in.	Layout Dimensions R_b in.
54	60 × 46	58½	48½	15.6	20½	18¾	29⅜	51⅛
60	66 × 51	65	54	19.3	22¾	20¾	32⅝	56¼
66	73 × 55	72½	58¼	23.2	25⅛	22⅞	36¾	63¾
72	81 × 59	79	62½	27.4	23¾	20⅞	39½	82⅝
78	87 × 63	86½	67¼	32.1	25¾	22⅝	43⅜	92¼
84	95 × 67	93½	71¾	37.0	27¾	24⅜	47	100¼
90	103 × 71	101½	76	42.4	29¾	26⅛	51¼	111⅝
96	112 × 75	108½	80½	48.0	31⅝	27¾	54⅞	120¼
102	117 × 79	116½	84¾	54.2	33⅝	29½	59⅜	131¾
108	128 × 83	123½	89¼	60.5	35⅝	31¼	63¼	139¾
114	137 × 87	131	93¾	67.4	37⅝	33	67⅜	149½
120	142 × 91	138½	98	74.5	39½	34¾	71⅝	162⅜

Figure 12.4.44 Standard Sizes for Corrugated Steel (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

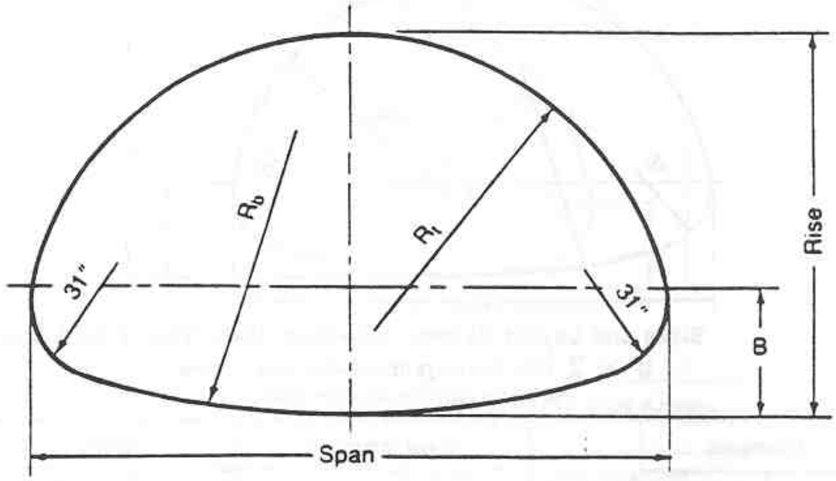


Sizes and Layout Details—Structural Plate Steel Pipe-Arches
6 × 2 in. Corrugations—Bolted Seams
18-inch Corner Radius Rc

Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
							Total	
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	N	Pi
6-1	4-7	22	21.0	3.07	6.36	5	22	66
6-4	4-9	24	20.5	3.18	8.22	5	23	69
6-9	4-11	26	22.0	3.42	6.96	5	24	72
7-0	5-1	28	21.4	3.53	8.68	5	25	75
7-3	5-3	31	20.8	3.63	11.35	6	26	78
7-8	5-5	33	22.4	3.88	9.15	6	27	81
7-11	5-7	35	21.7	3.98	11.49	6	28	84
8-2	5-9	38	20.9	4.08	15.24	6	29	87
8-7	5-11	40	22.7	4.33	11.75	7	30	90
8-10	6-1	43	21.8	4.42	14.89	7	31	93
9-4	6-3	46	23.8	4.68	12.05	7	32	96
9-6	6-5	49	22.9	4.78	14.79	7	33	99
9-9	6-7	52	21.9	4.86	18.98	7	34	102
10-3	6-9	55	23.9	5.13	14.86	7	35	105
10-8	6-11	58	26.1	5.41	12.77	7	36	108
10-11	7-1	61	25.1	5.49	15.03	7	37	111
11-5	7-3	64	27.4	5.78	13.16	7	38	114
11-7	7-5	67	26.3	5.85	15.27	8	39	117
11-10	7-7	71	25.2	5.93	18.03	8	40	120
12-4	7-9	74	27.5	6.23	15.54	8	41	123
12-6	7-11	78	26.4	6.29	18.07	8	42	126
12-8	8-1	81	25.2	6.37	21.45	8	43	129
12-10	8-4	85	24.0	6.44	26.23	8	44	132
13-5	8-5	89	26.3	6.73	21.23	9	45	135
13-11	8-7	93	28.9	7.03	18.39	9	46	138
14-1	8-9	97	27.6	7.09	21.18	9	47	141
14-3	8-11	101	26.3	7.16	24.80	9	48	144
14-10	9-1	105	28.9	7.47	21.19	9	49	147
15-4	9-3	109	31.6	7.78	18.90	9	50	150
15-6	9-5	113	30.2	7.83	21.31	10	51	153
15-8	9-7	118	28.8	7.89	24.29	10	52	156
15-10	9-10	122	27.4	7.96	28.18	10	53	159
16-5	9-11	126	30.1	8.27	24.24	10	54	162
16-7	10-1	131	28.7	8.33	27.73	10	55	165

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



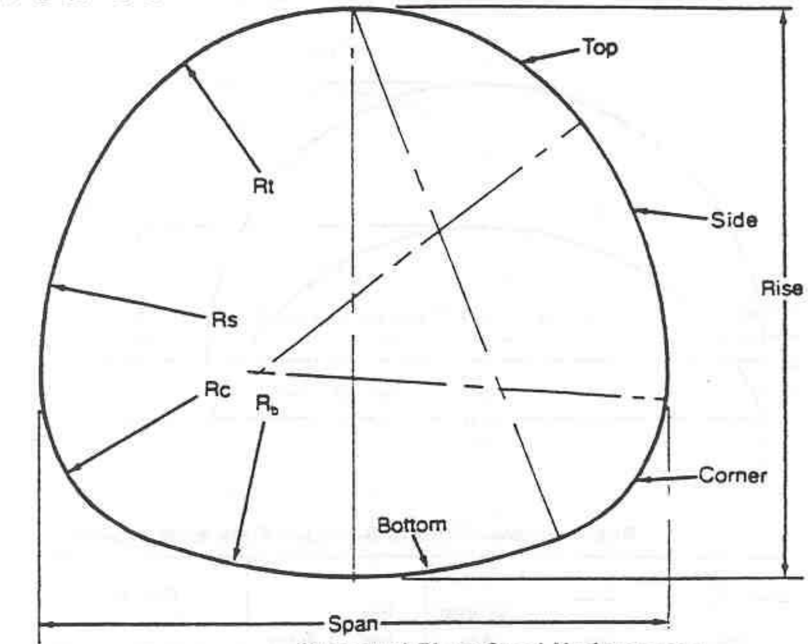
Sizes and Layout Details—Structural Plate Steel Pipe-Arches[11]
6 × 2 in. Corrugations—Bolted Seams
31-in Corner Radius, R_c

Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	Total N	Total Pi
13-3	9-4	97	38.5	6.68	16.05	8	46	138
13-6	9-6	102	37.7	6.78	18.33	8	47	141
14-0	9-8	105	39.6	7.03	16.49	8	48	144
14-2	9-10	109	38.8	7.13	18.55	8	49	147
14-5	10-0	114	37.9	7.22	21.38	8	50	150
14-11	10-2	118	39.8	7.48	18.98	9	51	153
15-4	10-4	123	41.8	7.76	17.38	9	52	156
15-7	10-6	127	40.9	7.84	19.34	10	53	159
15-10	10-8	132	40.0	7.93	21.72	10	54	162
16-3	10-10	137	42.1	8.21	19.67	10	55	165
16-6	11-0	142	41.1	8.29	21.93	10	56	168
17-0	11-2	146	43.3	8.58	20.08	10	57	171
17-2	11-4	151	42.3	8.65	22.23	10	58	174
17-5	11-6	157	41.3	8.73	24.83	10	59	177
17-11	11-8	161	43.5	9.02	22.55	10	60	180
18-1	11-10	167	42.4	9.09	24.98	10	61	183
18-7	12-0	172	44.7	9.38	22.88	10	62	186
18-9	12-2	177	43.6	9.46	25.19	10	63	189
19-3	12-4	182	45.9	9.75	23.22	10	64	192
19-6	12-6	188	44.8	9.83	25.43	11	65	195
19-8	12-8	194	43.7	9.90	28.04	11	66	198
19-11	12-10	200	42.5	9.98	31.19	11	67	201
20-5	13-0	205	44.9	10.27	28.18	11	68	204
20-7	13-2	211	43.7	10.33	31.13	12	69	207

Dimensions are to inside crests and are subject to manufacturing tolerances.
$N = 3$ Pi $= 9.6$ in.

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



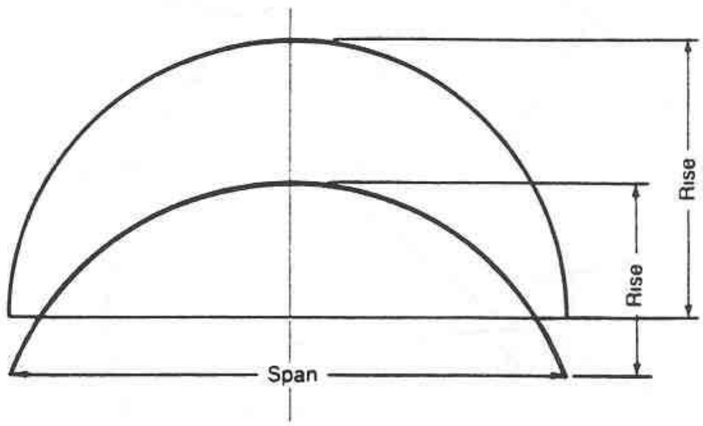
Structural Plate Steel Underpasses
Sizes and Layout Details

Span × Rise, ft and in.		Periphery			Layout Dimensions in In.			
		N	Pi	No. of Plates per Ring	R_t	R_s	R_c	R_b
5-8	5-9	24	72	6	27	53	18	Flat
5-8	6-6	26	78	6	29	75	18	Flat
5-9	7-4	28	84	6	28	95	18	Flat
5-10	7-8	29	87	7	30	112	18	Flat
5-10	8-2	30	90	6	28	116	18	Flat
12-2	11-0	47	141	8	68	93	38	136
12-11	11-2	49	147	9	74	92	38	148
13-2	11-10	51	153	11	73	102	38	161
13-10	12-2	53	159	11	77	106	38	168
14-1	12-10	55	165	11	77	115	38	183
14-6	13-5	57	171	11	78	131	38	174
14-10	14-0	59	177	11	79	136	38	193
15-6	14-4	61	183	12	83	139	38	201
15-8	15-0	63	189	12	82	151	38	212
16-4	15-5	65	195	12	86	156	38	217
16-5	16-0	67	201	12	88	159	38	271
16-9	16-3	68	204	12	89	168	38	246
17-3	17-0	70	210	12	90	174	47	214
18-4	16-11	72	216	12	99	157	47	248
19-1	17-2	74	222	13	105	156	47	262
19-6	17-7	76	228	13	107	158	47	295
20-4	17-9	78	234	13	114	155	47	316

All dimensions, to nearest whole number, are measured from inside crests.
Tolerances should be allowed for specification purposes. 6 × 2 in. Corrugations.

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Representative Sizes of Structural Plate Steel Arches

Dimensions[1] Span, ft	Dimensions[1] Rise, ft-in.	Waterway Area, ft²	Rise over Span[2]	Radius, in.	Nominal Arc Length N[3]	Nominal Arc Length Pi, in.
6.0	1-9½	7½	0.30	41	9	27
	2-3½	10	0.38	37½	10	30
	3-2	15	0.53	36	12	36
7.0	2-4	12	0.34	45	11	33
	2-10	15	0.40	43	12	36
	3-8	20	0.52	42	14	42
8.0	2-11	17	0.37	51	13	39
	3-4	20	0.42	48½	14	42
	4-2	26	0.52	48	16	48
9.0	2-11	18½	0.32	59	14	42
	3-10½	26½	0.43	55	16	48
	4-8½	33	0.52	54	18	54
10.0	3-5½	25	0.35	64	16	48
	4-5	34	0.44	60½	18	54
	5-3	41	0.52	60	20	60
11.0	3-6	27½	0.32	73	17	51
	4-5½	37	0.41	67½	19	57
	5-9	50	0.52	66	22	66
12.0	4-0½	35	0.34	77½	19	57
	5-0	45	0.42	73	21	63
	6-3	59	0.52	72	24	72
13.0	4-1	38	0.32	86½	20	60
	5-1	49	0.39	80½	22	66
	6-9	70	0.52	78	26	78
14.0	4-7½	47	0.33	91	22	66
	5-7	58	0.40	86	24	72
	7-3	80	0.52	84	28	84

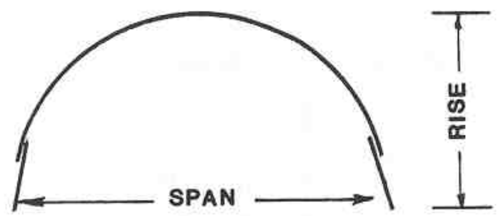
(Table continued on following page)

[1]Dimensions are to inside crests and are subject to manufacturing tolerances.
[2]R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
[3]W = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

ARCH



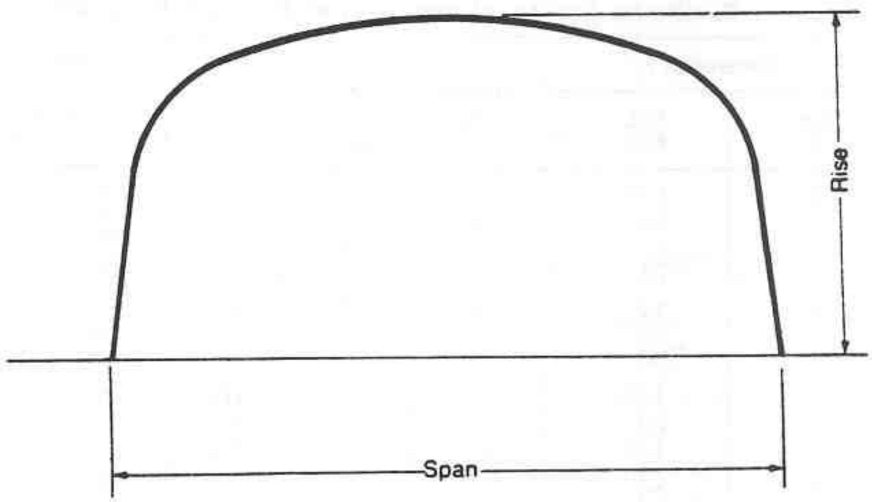
Continued. Representative Sizes of Structural Plate Steel Arches

Dimensions(1)		Waterway Area, ft²	Rise over Span(2)	Radius, in.	Nominal Arc Length	
Span, ft	Rise, ft-in.				N(3)	Pi, in.
15.0	4-7½	50	0.31	101	23	69
	5-8	62	0.38	93	25	75
	6-7	75	0.44	91	27	81
	7-9	92	0.52	90	30	90
16.0	5-2	60	0.32	105	25	75
	7-1	86	0.45	97	29	87
	8-3	105	0.52	96	32	96
17.0	5-2½	63	0.31	115	26	78
	7-2	92	0.42	103	30	90
	8-10	119	0.52	102	34	102
18.0	5-9	75	0.32	119	28	84
	7-8	104	0.43	109	32	96
	8-11	126	0.50	108	35	105
19.0	6-4	87	0.33	123	30	90
	8-2	118	0.43	115	34	102
	9-5½	140	0.50	114	37	111
20.0	6-4	91	0.32	133	31	93
	8-3½	124	0.42	122	35	105
	10-0	157	0.50	120	39	117
21.0	6-11	104	0.33	137	33	99
	8-10	140	0.42	128	37	111
	10-6	172	0.50	126	41	123
22.0	6-11	109	0.31	146	34	102
	8-11	146	0.40	135	38	114
	11-0	190	0.50	132	43	129
23.0	8-0	134	0.35	147	37	111
	9-10	171	0.43	140	41	123
	11-6	208	0.50	138	45	135
24.0	8-6	150	0.35	152	39	117
	10-4	188	0.43	146	43	129
	12-0	226	0.50	144	47	141
25.0	8-6½	155	0.34	160	40	120
	10-10½	207	0.43	152	45	135
	12-6	247	0.50	150	49	147

(1)Dimensions are to inside crests and are subject to manufacturing tolerances.
(2)R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
(3)N = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Layout Details
Corrugated Steel Box Culverts

Rise, ft-in.	Span, ft-in.	Area ft²	Rise, ft-in.	Span, ft-in.	Area ft²
2-7	9-8	20.8	3-9	12-10	41.0
2-8	10-5	23.2	3-10	13-6	44.5
2-9	11-1	25.7	3-10	17-4	55.0
2-10	11-10	28.3	3-11	14-2	48.2
2-11	12-6	31.1	3-11	18-0	59.1
3-1	13-3	34.0	4-1	14-10	52.0
3-2	13-11	37.1	4-1	18-8	63.4
3-3	14-7	40.4	4-2	10-7	36.4
3-4	10-1	28.4	4-2	15-6	55.9
3-5	10-10	31.4	4-3	11-2	39.9
3-5	15-3	43.8	4-3	19-4	67.9
3-6	11-6	34.5	4-4	11-10	43.5
3-6	16-0	47.3	4-4	16-2	60.1
3-8	12-2	37.7	4-5	12-6	47.3
3-8	16-8	51.1	4-6	13-2	51.2

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

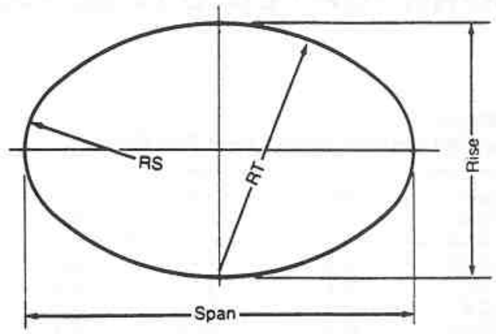
STANDARD SIZES FOR CORRUGATED STEEL CULVERTS

Continued.
Layout Details Corrugated Steel Box Culverts

Rise, ft-in.	Span, ft-in.	Area ft²	Rise, ft-in.	Span, ft-in.	Area ft²
4-6	16-10	64.4	6-9	13-7	77.9
4-7	17-6	68.9	6-9	16-9	99.3
4-7	20-8	77.6	6-10	14-2	83.3
4-8	13-10	55.3	6-10	17-4	105.1
4-9	14-6	59.5	7-0	14-9	88.9
4-9	18-1	73.5	7-0	17-11	111.1
4-10	15-1	63.8	7-0	20-8	127.2
4-11	11-0	44.7	7-1	15-4	94.6
4-11	18-9	78.4	7-2	18-6	117.3
5-0	11-7	48.7	7-3	12-3	71.5
5-0	15-9	68.3	7-3	15-10	100.5
5-1	12-3	52.9	7-4	12-10	77.1
5-1	16-4	73.0	7-4	16-5	106.5
5-1	19-5	83.4	7-4	19-1	123.6
5-2	12-10	57.2	7-5	13-5	82.8
5-3	17-0	77.8	7-6	13-11	88.6
5-4	13-6	61.7	7-6	17-0	112.7
5-5	14-1	66.2	7-8	14-6	94.5
5-5	17-7	82.8	7-8	17-6	119.0
5-5	20-8	94.1	7-9	15-0	100.6
5-6	14-9	71.0	7-9	18-1	125.5
5-7	18-3	88.0	7-11	15-7	106.8
5-8	11-5	53.3	7-11	18-7	132.1
5-8	15-4	75.8	8-0	12-8	81.1
5-8	18-10	93.4	8-0	16-1	113.1
5-9	12-0	57.9	8-1	19-2	138.9
5-9	16-0	80.9	8-2	16-8	119.6
5-10	12-7	62.6	8-2	13-9	93.3
5-10	19-6	98.9	8-3	19-8	145.9
5-11	16-7	86.1	8-4	17-2	126.2
6-0	13-3	67.4	8-5	14-10	106.0
6-1	13-10	72.4	8-5	17-8	133.0
6-1	17-2	91.4	8-7	18-3	139.9
6-2	14-5	77.5	8-7	20-9	160.3
6-2	17-9	96.9	8-8	15-10	119.2
6-2	20-8	110.6	8-9	18-9	147.0
6-4	15-0	82.7	8-11	16-10	132.9
6-4	18-4	102.6	8-11	19-3	154.2
6-5	11-10	62.2	9-1	19-9	161.6
6-5	15-7	88.1	9-3	17-10	147.1
6-6	18-11	108.5	9-5	20-9	176.9
6-7	12-5	67.3	9-6	18-10	162.0
6-7	16-2	93.6	9-10	19-10	177.4
6-8	13-0	72.5	10-2	20-9	193.5
6-8	19-6	114.5			

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR CORRUGATED STEEL CULVERTS

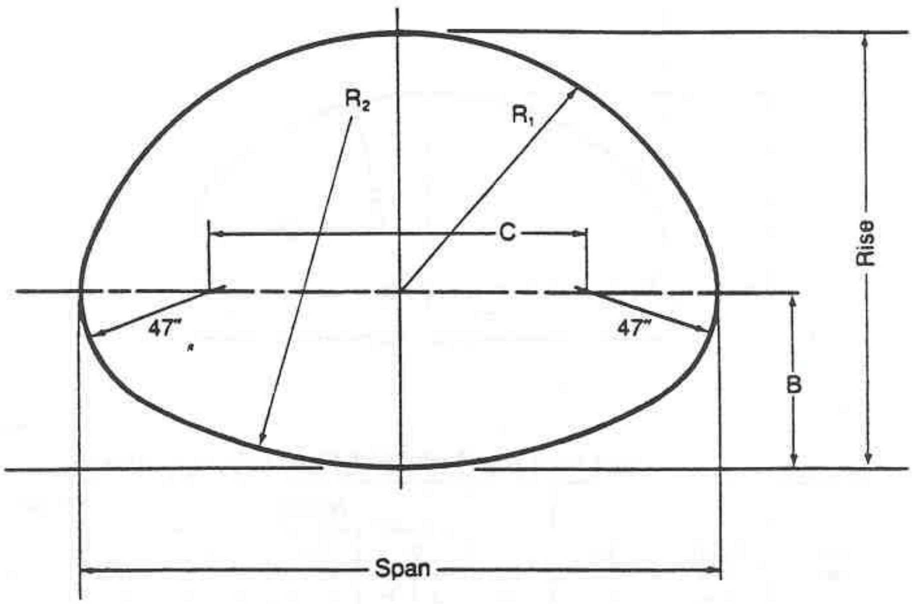


Long Span Horizontal Ellipse Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Periphery						Inside Radius	
			Top or Bottom		Side		Total		Top Rad. in.	Side Rad. in.
			N	Pi	*N*	Pi	*N*	Pi		
19- 4	12- 9	191	22	66	10	30	64	192	12- 6	4- 6
20- 1	13- 0	202	23	69	10	30	66	198	13- 1	4- 6
20- 2	11-11	183	24	72	8	24	64	192	13- 8	3- 7
20-10	12- 2	194	25	75	8	24	66	198	14- 3	3- 7
21- 0	15- 2	248	23	69	13	39	72	216	13- 1	5-11
21-11	13- 1	221	26	78	9	27	70	210	14-10	4- 1
22- 6	15- 8	274	25	75	13	39	76	228	14- 3	5-11
23- 0	14- 1	249	27	81	10	30	74	222	15- 5	4- 6
23- 3	15-11	288	26	78	13	39	78	234	14-10	5-11
24- 4	16-11	320	27	81	14	42	82	246	15- 5	6- 4
24- 6	14- 8	274	29	87	10	30	78	234	16- 6	4- 6
25- 2	14-11	287	30	90	10	30	80	240	17- 1	4- 6
25- 5	16- 9	330	29	87	13	39	84	252	16- 6	5-11
26- 1	18- 2	369	29	87	15	45	88	264	16- 6	6-10
26- 3	15-10	320	31	93	11	33	84	252	17- 8	4-11
27- 0	16- 2	334	32	96	11	33	86	258	18- 3	4-11
27- 2	19- 1	405	30	90	16	48	92	276	17- 1	7- 3
27-11	19- 5	421	31	92	16	48	94	282	17- 8	7- 3
28- 1	17- 1	369	33	99	12	36	90	270	18-10	5- 5
28-10	17- 5	384	34	102	12	36	92	276	19- 5	5- 5
29- 5	19-11	455	33	99	16	48	98	294	18-10	7- 3
30- 1	20- 2	472	34	102	16	48	100	300	19- 5	7- 3
30- 3	17-11	415	36	108	12	36	96	288	20- 7	5- 5
31- 2	21- 2	512	35	105	17	51	104	312	20- 0	7- 9
31- 4	18-11	454	37	111	13	39	100	300	21- 1	5-11
32- 1	19- 2	471	38	114	13	39	102	306	21- 8	5-11
32- 3	22- 2	555	36	108	18	54	108	324	20- 7	8- 2
33- 0	22- 5	574	37	111	18	54	110	330	21- 1	8- 2
33- 2	20- 1	512	39	117	14	42	106	318	22- 3	6- 4
34- 1	23- 4	619	38	114	19	57	114	342	21- 8	8- 8
34- 7	20- 8	548	41	123	14	42	110	330	23- 5	6- 4
34-11	21- 4	574	41	123	15	45	112	336	23- 5	6-10
35- 1	24- 4	665	39	117	20	60	118	354	22- 3	9- 1
35- 9	25- 9	718	39	117	22	66	122	366	22- 3	10- 0
36- 0	22- 4	619	42	126	16	48	116	348	24- 0	7- 3
36-11	25- 7	735	41	123	21	63	124	372	23- 5	9- 7
37- 2	22- 2	631	44	132	15	45	118	354	25- 2	6-10
38- 0	26- 7	785	44	132	22	66	128	384	24- 0	10- 0
38- 8	27-11	843	42	126	24	72	132	396	24- 0	10-11
40- 0	29- 7	927	43	129	26	78	138	414	27-11	11-10

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR CORRUGATED STEEL CULVERTS



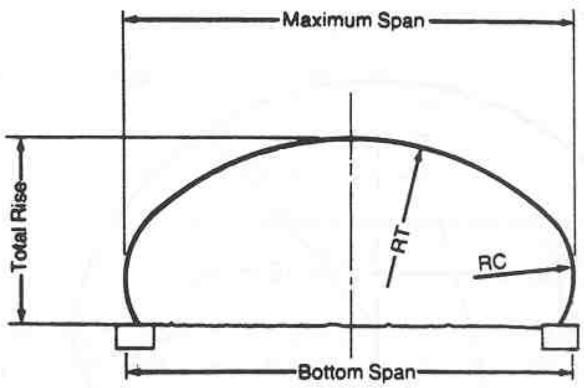
Long Span Pipe Arch Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Total No. Plates	Periphery Top N	Top Pi	Bottom N	Bottom Pi	Total N	Total Pi	B, in.	C, in.	Inside Radius R_1, in.	R_2, in.
20- 0	13-11	218	10	34	102	20	60	68	204	62.8	146.2	122.5	223.6
20- 6	14- 3	231	10	36	108	20	60	70	210	61.4	152.3	124.7	255.7
21- 5	14- 6	243	11	36	108	22	66	72	216	65.3	162.8	131.4	236.7
21-11	14-11	256	11	38	114	22	66	74	222	63.7	168.9	133.5	268.1
22- 5	15- 3	270	11	40	120	22	66	76	228	62.1	174.6	135.5	307.1
23- 4	15- 7	284	11	40	120	24	72	78	234	66.2	185.5	142.4	280.2
24- 2	15-11	297	12	40	120	26	78	80	240	70.7	196.2	149.7	262.1
24- 8	16- 2	312	12	42	126	26	78	82	246	68.8	202.2	151.4	292.2
25- 2	16- 7	326	12	44	132	26	78	84	252	66.9	207.9	153.2	328.6
25- 7	16-11	342	12	46	138	26	78	86	258	64.8	213.3	155.0	373.3
26- 7	17- 3	357	12	46	138	28	84	88	264	69.4	224.7	162.1	339.4
27- 6	17- 6	372	12	46	138	30	90	90	270	74.2	235.8	169.6	315.8
28- 0	17-10	388	12	48	144	30	90	92	276	72.1	241.5	171.1	350.2
28- 5	18- 3	405	13	50	150	30	90	94	282	69.9	246.8	172.7	392.3
29- 4	18- 6	421	13	50	150	32	96	96	288	74.8	258.2	180.2	361.1
30- 4	18-10	438	14	52	156	34	102	100	300	80.0	269.4	188.2	339.1

*Includes 14N for two N7 corner plates

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



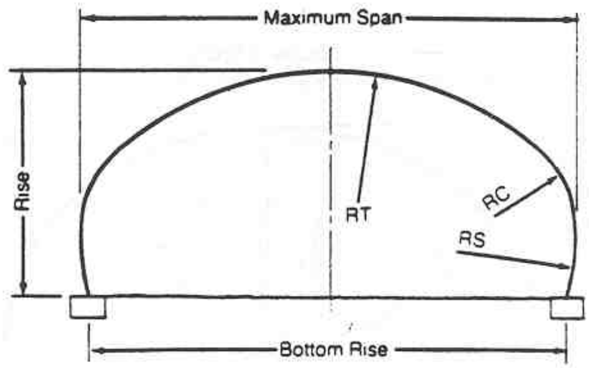
Long Span Low Profile Arch Sizes and Layout Details

Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft²	Periphery						Inside Radius	
				Top		Side		Total		Top rad. in.	Side rad. in.
				N	Pi	N	Pi	N	Pi		
20- 1	19-10	7- 6	121	23	69	6	18	35	105	13- 1	4- 6
19- 5	19- 1	6-10	105	23	69	5	15	33	99	13- 1	3- 7
21- 6	21- 4	7- 9	134	25	75	6	18	37	111	14- 3	4- 6
22- 3	22- 1	7-11	140	26	78	6	18	38	114	14-10	4- 6
23- 0	22- 9	8- 0	147	27	81	6	18	39	117	15- 5	4- 6
23- 9	23- 6	8- 2	154	28	84	6	18	40	120	16- 0	4- 6
24- 6	24- 3	8- 4	161	29	87	6	18	41	123	16- 6	4- 6
25- 2	25- 0	8- 5	169	30	90	6	18	42	126	17- 1	4- 6
25-11	25- 9	8- 7	176	31	93	6	18	43	129	17- 8	4- 6
27- 3	27- 1	10- 0	217	31	93	8	24	47	141	17- 8	6- 4
28- 1	27-11	9- 7	212	33	99	7	21	47	141	18-10	5- 5
28- 9	28- 7	10- 3	234	33	99	8	24	49	147	18-10	6- 4
28-10	28- 8	9- 8	221	34	102	7	21	48	144	19- 5	5- 5
30- 3	30- 1	9-11	238	36	108	7	21	50	150	20- 7	5- 5
30-11	30- 9	10- 8	261	36	108	8	24	52	156	20- 7	6- 4
31- 7	31- 2	12- 1	309	36	108	10	30	56	168	20- 7	7- 3
31- 0	30-10	10- 1	246	37	111	7	21	51	153	21- 1	5- 5
32- 4	31-11	12- 3	320	37	111	10	30	57	171	21- 1	7- 3
31- 9	31- 7	10- 3	255	38	114	7	21	52	156	21- 8	5- 5
33- 1	32- 7	12- 5	330	38	114	10	30	58	174	21- 8	7- 3
33- 2	33- 0	11- 1	289	39	117	8	24	55	165	22- 3	6- 4
34- 5	34- 1	13- 3	377	39	117	11	33	61	183	22- 3	8- 2
34- 7	34- 6	11- 4	308	41	123	8	24	57	183	23- 5	6- 4
37-11	37- 7	15- 8	477	41	123	14	42	69	207	23- 5	10-11
35- 4	35- 2	11- 5	318	42	126	8	24	58	174	24- 0	6- 4
38- 8	38- 4	15- 9	490	42	126	14	42	70	210	24- 0	10-11

NOTE: Larger sizes available for special designs.

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

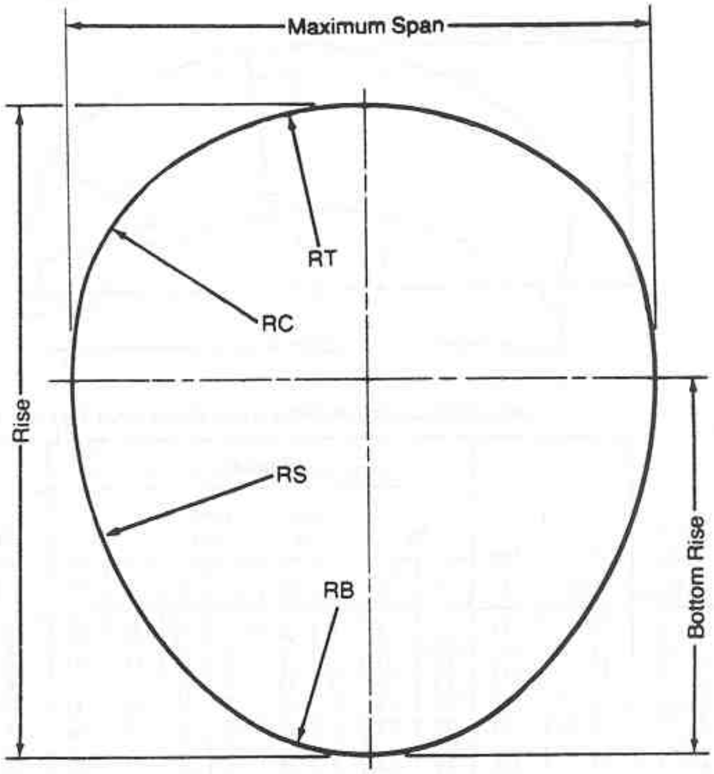


Long Span High Profile Arch Sizes and Layout Details

Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft²	Periphery								Inside Radius		
				Top		Upper Side		Lower Side		Total		Top Radius, ft-in.	Upper Side, ft-in.	Lower Side, ft-in.
				N	Pi	N	Pi	N	Pi	N	Pi			
20- 1	19- 6	9- 1	152	23	69	5	15	3	9	39	117	13- 1	4- 6	13- 1
20- 8	18-10	12- 1	214	23	69	6	18	6	18	47	141	13- 1	5- 5	13- 1
21- 6	19-10	11- 8	215	25	75	5	15	6	18	47	141	14- 3	4- 6	14- 3
22-10	19-10	14- 7	285	25	75	7	21	8	24	55	165	14- 3	6- 4	14- 3
22- 3	20- 7	11-10	225	26	78	5	15	6	18	48	144	14-10	4- 6	14-10
22-11	20- 0	14- 0	276	26	78	6	18	8	24	54	162	14-10	5- 5	14-10
23- 0	21- 5	12- 0	235	27	81	5	15	6	18	49	147	15- 5	4- 6	15- 5
24- 4	21- 6	14-10	310	27	81	7	21	8	24	57	171	15- 5	6- 4	15- 5
23- 9	22- 2	12- 1	245	28	84	5	15	6	18	50	150	16- 0	4- 6	16- 0
24- 6	21-11	13- 9	289	29	87	5	15	8	24	55	165	16- 6	4- 6	16- 6
25- 9	23- 2	15- 2	335	29	87	7	21	8	24	59	177	16- 6	6- 4	16- 6
25- 2	23- 3	13- 2	283	30	90	5	15	7	21	54	162	17- 1	4- 6	17- 1
26- 6	24- 0	15- 3	348	30	90	7	21	8	24	60	180	17- 1	6- 4	17- 1
25-11	24- 1	13- 3	295	31	93	5	15	7	21	55	165	17- 8	4- 6	17- 8
27- 3	24-10	15- 5	360	31	93	7	21	8	24	61	183	17- 8	6- 4	17- 8
27- 5	25- 8	13- 7	317	33	99	5	15	7	21	57	171	18-10	4- 6	18-10
29- 5	27- 1	16- 5	412	33	99	8	28	8	24	65	195	18-10	7- 3	18-10
28- 2	25-11	14- 5	349	34	102	5	15	8	24	60	180	19- 5	4- 6	19- 5
30- 1	26- 9	18- 1	467	34	102	8	24	10	30	70	210	19- 5	7- 3	19- 5
30- 3	28- 2	15- 5	399	36	108	6	18	8	24	64	192	20- 7	5- 5	20- 7
31- 7	28- 4	18- 4	497	36	108	8	24	10	30	72	216	20- 7	7- 3	20- 7
31- 0	29- 0	15- 7	413	37	111	6	18	8	24	65	195	21- 1	5- 5	21- 1
31- 8	28- 6	17- 9	484	37	111	7	21	10	30	71	213	21- 1	6- 4	21- 1
32- 4	27-11	19-11	554	37	111	8	24	12	36	77	231	21- 1	7- 3	21- 1
31- 9	28- 8	17- 3	470	38	114	6	18	10	30	70	210	21- 8	5- 5	21- 8
33- 1	28- 9	20- 1	571	38	114	8	24	12	36	78	234	21- 8	7- 3	21- 8
32- 6	29- 6	17- 4	484	39	117	6	18	10	30	71	213	22- 3	5- 5	22- 3
33-10	29- 7	20- 3	588	39	117	8	24	12	36	79	237	22- 3	7- 3	22- 3
34- 0	31- 2	17- 8	514	41	123	6	18	10	30	73	219	23- 5	5- 5	23- 5
34- 7	30- 7	19-10	591	41	123	7	21	12	36	79	237	23- 5	6- 4	23- 5
35- 3	30- 7	21- 3	645	41	123	8	24	13	39	83	249	23- 5	7- 3	23- 5
37- 3	32- 6	23- 5	747	41	123	11	33	13	39	89	267	23- 5	10- 0	23- 5
34- 8	31-11	17-10	529	42	126	6	18	10	30	74	222	24- 0	5- 5	24- 0
35- 4	31- 5	20- 0	608	42	126	7	21	12	36	80	240	24- 0	6- 4	24- 0
36- 0	31- 5	21- 5	663	42	126	8	24	13	39	84	252	24- 0	7- 3	24- 0
38- 0	33- 5	23- 6	767	42	126	11	33	13	39	90	270	24- 0	10- 0	24- 0

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR CORRUGATED STEEL CULVERTS



Long Span Pear Shape Sizes and Layout Details

Max. Span, ft-in.	Rise, ft-in.	Rise Bottom, ft-in.	Area	Periphery: Top N	Top Pi	Corner N	Corner Pi	Side N	Side Pi	Bottom N	Bottom Pi	Total N	Total Pi	Inside Radius: Bottom Radius, ft-in.	Side Radius, ft-in.	Corner Radius, ft-in.	Top Radius, ft-in.
23- 8	25- 8	14-11	481	25	75	5	15	24	72	15	30	98	294	8-11	16- 7	6- 3	14- 8
24- 0	25-10	15- 1	496	22	66	7	21	22	66	20	60	100	300	9-11	17- 4	7- 0	16- 2
25- 6	25-11	15-10	521	27	81	7	21	20	60	21	63	102	306	10- 7	18- 1	6-11	15-10
24-10	27- 8	16- 9	544	27	81	5	15	25	75	18	54	105	315	9- 3	19- 8	5- 9	15-11
27- 5	27- 0	18- 1	578	30	90	6	18	26	78	16	48	110	330	9- 7	20- 4	4- 7	19-11
26- 8	28- 3	18- 0	593	28	84	5	15	30	90	12	36	110	330	8- 0	20- 1	4- 9	20-11
28- 1	27-10	16-10	624	27	81	8	24	22	66	25	75	112	336	12- 2	19- 0	7- 3	20- 5
28- 7	30- 7	19- 7	689	32	96	7	21	24	72	24	72	118	354	11- 2	24- 0	7- 0	18- 2
30- 0	29- 8	20- 0	699	32	96	8	24	23	69	25	75	119	357	11-11	24- 0	6- 7	21-10
30- 0	31- 2	19-11	736	34	102	7	21	24	72	26	78	122	366	12- 1	24- 0	7- 0	19- 3

Figure 12.4.44 Standard Sizes for Corrugated Steel Culverts (Source: American Iron and Steel Institute), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Helical Pipe Availability, Weights

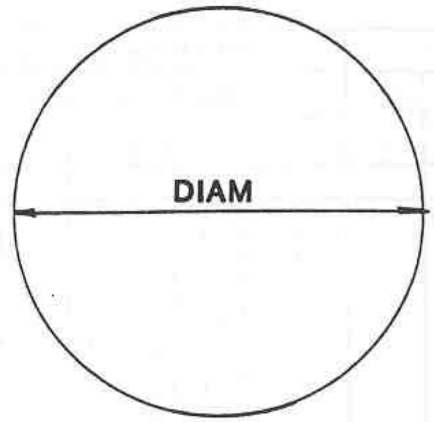
CORR. PATTERN				WEIGHT (Lbs./Lineal Ft.)					
				Equiv. Standard Gauge					
1-1/2 x 1/4	2-2/3 x 1/2	3 x 1	6" x 1	18	16	14	12	10	8
Diameter (In.)									
6				1.4	1.7				
8				1.8	2.2				
10				2.2	2.7				
	12				3.2	4.0	5.5		
	15				3.9	4.9	6.8		
	18				4.7	5.9	8.1		
	21				5.4	6.8	9.4		
	24				6.2	7.8	10.7	13.8	
	27				7.0	8.7	12.1	15.4	
	30				7.8	9.6	13.4	17.1	
		30			8.9	11.2	15.5	19.9	
	36					11.5	16.0	20.5	
		36			10.7	13.4	18.5	23.7	
	42						18.6	23.8	
		42			12.4	15.5	21.5	27.5	
	48						21.2	27.2	32.7
		48			14.1	17.7	24.5	31.4	37.8
			48		12.5	15.6	21.8	28.1	34.1
	54						23.8	30.5	36.7
		54			15.8	19.9	27.5	35.2	42.4
			54		14.0	17.5	24.5	31.5	38.3
	60							33.9	40.8
		60			17.6	22.0	30.5	39.0	47.0
			60		15.5	19.4	27.2	34.9	42.5
	66							37.2	44.8
		66			17.0	21.3	29.8	38.4	46.6
	72								48.8
		72				26.3	36.5	46.7	56.2
			72			23.2	32.5	41.8	50.8
	78								52.9
		78				28.5	39.5	50.5	60.8
			78			25.1	35.2	45.2	55.0
	84								56.9
		84				30.7	42.5	54.3	65.4
			84				37.8	48.7	59.1
		90					45.4	58.2	70.0
			90				40.5	52.1	63.3
		96					48.4	62.0	74.6
			96				43.2	55.5	67.5
		102					51.4	65.8	79.3
			102				45.8	58.9	71.6
		108					54.4	69.7	83.9
			108				48.5	62.4	75.8
		114					57.4	73.5	88.5
			114				51.2	65.8	80.0
		120					60.4	77.3	93.1
			120				53.8	69.2	84.1

NOTES: 1. Sizes 6" thru 10" are available in helical corrugation only.

2. Sizes 12" through 21" in helical configuration have corrugation depth of 7/16" rather than 1/2".

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association)

STANDARD SIZES FOR ALUMINUM CULVERTS



Geometric Data — Structural Plate Pipe

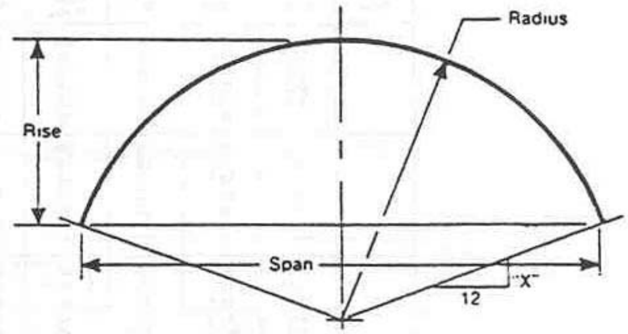
Nom. Diam. In.	Area Sq. Ft.	Total N	Nom. Diam. In.	Area Sq. Ft.	Total N
60	19	20	162	145	54
66	23	22	168	156	56
72	27	24	174	167	58
78	32	26	180	179	60
84	38	28	186	191	62
90	44	30	192	204	64
96	50	32	198	217	66
102	56	34	204	231	68
108	63	36	210	245	70
114	71	38	216	259	72
120	79	40	222	274	74
126	87	42	228	289	76
132	95	44	234	305	78
138	104	46	240	321	80
144	114	48	246	337	82
150	124	50	252	354	84
156	134	52	—	—	—

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

GEOMETRIC DATA – ARCH

"X" Values For Rise/Span Ratio			
R/S Ratio	"X"	R/S Ratio	"X"
.30	6.40	.42	2.10
.31	5.96	.43	1.82
.32	5.54	.44	1.54
.33	5.13	.45	1.27
.34	4.74	.46	1.00
.35	4.37	.47	.74
.36	4.01	.48	.48
.37	3.67	.49	.24
.38	3.33	.50	.00
.39	3.01	.51	.24
.40	2.70	.52	.47
.41	2.40		

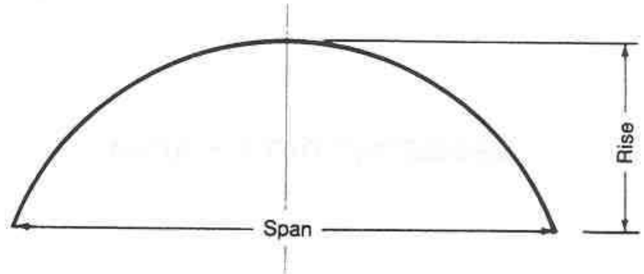


Typical Section

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/Span Ratio	Radius Inches
5-0	2-7	10.4	10	.52	30
	2-3	8.5	9	.44	30¼
	1-9	6.5	8	.36	31¾
6-0	3-2	14.9	12	.52	36
	2-9	12.6	11	.46	36¼
	2-4	10.2	10	.38	37¼
	1-10	7.8	9	.30	40½
7-0	3-8	20.3	14	.52	42
	3-3	17.5	13	.46	42
	2-10	14.8	12	.40	43
	2-4	12.0	11	.34	45¼
8-0	4-2	26.4	16	.52	48
	3-9	23.3	15	.47	48
	3-4	20.2	14	.42	48¼
	2-11	17.0	13	.36	50½
	2-5	13.6	12	.30	54½
9-0	4-8	33.4	18	.50	54
	4-3	29.9	17	.48	54
	3-10	26.3	16	.43	54½
	3-5	22.8	15	.38	56
	2-11	19.1	14	.33	59
10-0	5-2	41.2	20	.52	60
	4-10	37.3	19	.48	60
	4-5	33.3	18	.44	60½
	3-11	29.4	17	.40	61½
	3-6	25.3	16	.35	64
	3-0	21.1	15	.30	68½
11-0	5-8	49.8	22	.52	66
	5-4	45.5	21	.48	66
	4-11	41.2	20	.45	66½
	4-6	36.8	19	.41	67½
	4-0	32.4	18	.36	69¼
	3-6	27.8	17	.32	72¾

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS



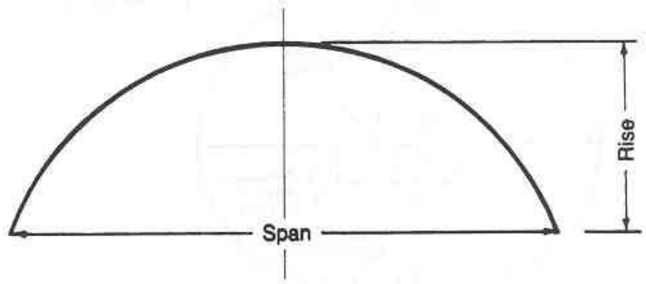
ARCH (CONT'D)

Geometric Data—Arch (Continued)

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
12-0	6-3	59.3	24	.52	72
	5-10	54.5	23	.49	72
	5-5	49.8	22	.45	72½
	5-0	45.0	21	.42	73¼
	4-7	40.2	20	.38	75
	4-1	35.3	19	.34	77½
13-0	6-9	69.5	26	.52	78
	6-4	64.4	25	.49	78
	5-11	59.3	24	.46	78¼
	5-6	54.1	23	.42	79
	5-1	48.9	22	.39	80½
	4-7	43.6	21	.35	82¾
	4-1	38.1	20	.31	86½
14-0	7-3	80.6	28	.52	84
	6-10	75.1	27	.49	84
	6-5	69.5	26	.46	84¼
	6-0	64.0	25	.43	85
	5-7	58.4	24	.40	86
	5-2	52.7	23	.37	88
	4-8	46.9	22	.33	91¼
15-0	7-9	92.5	30	.52	90
	7-5	86.5	29	.49	90
	7-0	80.6	28	.46	90¼
	6-7	74.7	27	.44	91
	6-1	68.7	26	.41	92
	5-8	62.6	25	.38	93½
	5-2	56.4	24	.34	96¼
	4-8	50.0	23	.31	100½
16-0	8-3	105.2	32	.52	96
	7-11	98.9	31	.49	96
	7-6	92.5	30	.47	96¼
	7-1	86.2	29	.44	96¾
	6-8	79.8	28	.41	97¾
	6-2	73.3	27	.39	99¼
	5-9	66.8	26	.36	101½
	5-3	60.0	25	.32	105
17-0	8-10	118.7	34	.52	102
	8-5	112.0	33	.49	102
	8-0	105.2	32	.47	102¼
	7-7	98.5	31	.45	102¾
	7-2	91.7	30	.42	103½
	6-9	84.9	29	.39	105
	6-3	77.9	28	.37	107
	5-9	70.9	27	.34	110
	5-3	63.5	26	.31	114¼
18-0	9-4	133.1	36	.52	108
	8-11	125.9	35	.50	108
	8-6	118.8	34	.47	108¼
	8-1	111.6	33	.45	108½
	7-8	104.5	32	.43	109¼
	7-3	97.2	31	.40	110½
	6-9	89.9	30	.38	112½
	6-4	82.5	29	.35	115
	5-9	74.8	28	.32	118¾
19-0	9-10	148.2	38	.52	114
	9-5	140.7	37	.50	114
	9-0	133.2	36	.48	114¼
	8-8	125.8	35	.45	114½
	8-2	118.0	34	.43	115¼
	7-9	110.4	33	.41	116¼
	7-4	102.7	32	.38	118
	6-10	94.9	31	.36	120¼
	6-4	86.9	30	.33	123½
	5-10	78.7	29	.31	128¼
20-0	10-4	164.2	40	.52	120
	10-0	156.3	39	.50	120
	9-7	148.3	38	.48	120
20-0 cont.	9-2	140.4	37	.46	120½
	8-9	132.4	36	.44	121
	8-3	124.4	35	.41	122¼
	7-10	116.3	34	.39	123½
	7-4	108.4	33	.37	125¾
	6-10	99.8	32	.34	128½
	6-4	91.2	31	.32	132½
21-0	10-10	181.0	42	.52	126
	10-6	172.7	41	.50	126
	10-1	164.3	40	.48	126
	9-8	156.0	39	.46	126½
	9-3	147.6	38	.44	127
	8-10	139.2	37	.42	128
	8-4	130.7	36	.40	129¼
	7-11	122.2	35	.38	131¼
	7-5	113.5	34	.35	133¾
	6-11	104.6	33	.33	137¼
	6-4	95.4	32	.30	142
22-0	11-5	198.6	44	.52	132
	11-0	189.9	43	.50	132
	10-7	181.1	42	.48	132
	10-2	172.4	41	.46	132½
	9-9	163.6	40	.44	133
	9-4	154.8	39	.42	133¾
	8-11	146.0	38	.40	135
	8-5	137.0	37	.38	135¾
	7-11	127.9	36	.36	139
	7-5	118.7	35	.34	142¼
	6-11	109.2	34	.31	142¼
23-0	11-11	217.1	46	.52	138
	11-6	207.9	45	.50	138
	11-1	198.8	44	.48	138
	10-8	189.5	43	.47	138¼
	10-3	180.5	42	.45	139
	9-10	171.3	41	.43	139½
	9-5	162.0	40	.41	140¾
	8-11	152.7	39	.39	142¼
	8-6	143.2	38	.37	144½
	8-0	133.6	37	.35	147¼
	7-6	123.8	36	.33	151
	6-11	113.8	35	.30	156
24-0	12-5	236.3	48	.52	144
	12-0	226.8	47	.50	144
	11-7	217.2	46	.48	144
	11-3	207.7	45	.47	144¼
	10-10	198.1	44	.45	144¾
	10-4	188.5	43	.43	145½
	9-11	178.9	42	.41	146½
	9-6	169.2	41	.39	148
	9-0	159.3	40	.38	150
	8-6	149.4	39	.36	152½
	8-0	139.2	38	.33	155¾
	7-6	128.9	37	.31	160¼
25-0	12-11	256.4	50	.52	150
	12-6	246.4	49	.50	150
	12-2	236.5	48	.49	150
	11-9	226.6	47	.47	150¼
	11-4	216.6	46	.45	150¾
	10-11	206.6	45	.44	151½
	10-5	196.6	44	.42	152½
	10-0	186.4	43	.40	153¾
	9-6	176.3	42	.38	155½
	9-1	165.9	41	.36	157¾
	8-7	155.4	40	.34	160¾
	8-1	144.7	39	.32	164¾
	7-6	133.7	38	.30	170
26-0	13-5	277.3	52	.52	156
	13-1	266.9	51	.50	156
	12-8	256.8	50	.49	156

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS



ARCH (CONT'D)

Geometric Data—Arch (Continued)

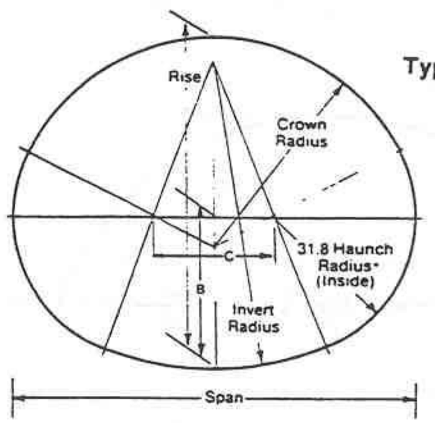
Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
26-0 cont.	12-3	246.2	49	.47	156¼
	11-10	235.9	48	.46	156¾
	11-5	225.5	47	.44	157¼
	11-0	215.1	46	.42	158¼
	10-6	204.6	45	.40	159½
	10-1	194.0	44	.39	161
	9-7	183.3	43	.37	163¼
	9-1	172.4	42	.35	166
	8-7	161.4	41	.33	169½
	8-1	150.1	40	.31	174
27-0	14-0	299.0	54	.52	162
	13-7	288.2	53	.50	162
	13-2	277.5	52	.49	162
	12-9	266.7	51	.47	162¼
	12-4	256.0	50	.46	162¾
	11-11	245.2	49	.44	163¼
	11-6	234.4	48	.43	164
	11-1	223.5	47	.41	165¼
	10-7	212.6	46	.39	166¾
	10-2	201.4	45	.38	168¾
	9-8	190.2	44	.36	171¼
	9-2	178.8	43	.34	174½
	8-7	167.2	42	.32	178½
	8-1	155.3	41	.30	183¾
28-0	14-6	321.5	56	.52	168
	14-1	310.4	55	.50	168
	13-8	299.2	54	.49	168
	13-3	288.1	53	.47	168¼
	12-10	276.9	52	.46	168½
	12-5	265.7	51	.44	169¼
	12-0	254.5	50	.43	170
	11-7	243.2	49	.41	171
	11-1	231.9	48	.40	172½
	10-8	220.4	47	.38	174¼
28-0 cont.	10-2	208.8	46	.36	176½
	9-8	197.1	45	.35	179½
	9-2	185.1	44	.33	183¼
	8-8	172.9	43	.31	188
29-0	15-0	344.8	58	.52	174
	14-7	333.3	57	.50	174
	14-2	321.7	56	.49	174
	13-10	310.2	55	.48	174¼
	13-5	298.6	54	.46	174½
	13-0	287.1	53	.45	175
	12-6	275.4	52	.43	175¾
	12-1	263.8	51	.42	176¾
	11-8	252.0	50	.40	178¼
	11-2	240.2	49	.39	180
	10-9	228.2	48	.37	182
	10-3	216.1	47	.35	184¾
	9-9	203.8	46	.34	188
	9-2	191.3	45	.32	192¼
	8-8	178.5	44	.30	197¾
30-0	15-6	369.0	60	.52	180
	15-1	357.1	59	.50	180
	14-9	345.1	58	.49	180
	14-4	333.2	57	.48	180¼
	13-11	321.2	56	.46	180½
	13-6	309.2	55	.45	181
	13-1	297.2	54	.44	181¾
	12-7	285.1	53	.42	182¾
	12-2	273.0	52	.41	184
	11-9	260.8	51	.39	185½
	11-3	248.5	50	.37	187½
	10-9	236.0	49	.36	190
	10-3	223.3	48	.34	193
	9-9	210.5	47	.32	197
	9-2	197.3	46	.31	201¾

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Geometric Data—Pipe Arch

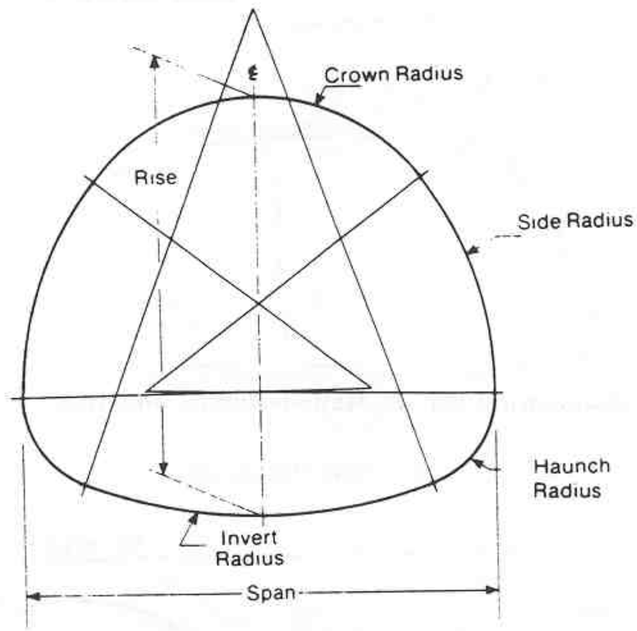
Typical Section



Span Ft.-In.	Rise Ft.-In.	Area Sq. Ft.	Required N Total	Required N Crown	Required N Invert	Required N Haunch	Inside Radius Crown In.	Inside Radius Invert In.	B	C
6-7	5-8	29.6	25	8	3	7	41.5	69.9	32.5	15.3
6-11	5-9	31.9	26	9	3	7	43.7	102.9	32.4	19.6
7-3	5-11	34.3	27	10	3	7	45.6	188.3	32.2	23.8
7-9	6-0	36.8	28	9	5	7	51.6	83.8	33.8	29.0
8-1	6-1	39.3	29	10	5	7	53.3	108.1	33.5	33.3
8-5	6-3	41.9	30	11	5	7	54.9	150.1	33.2	37.4
8-10	6-4	44.5	31	10	7	7	63.3	93.0	35.6	42.8
9-3	5-5	47.1	32	11	7	7	64.4	112.6	35.2	47.1
9-7	6-6	49.9	33	12	7	7	65.4	141.6	34.7	51.3
9-11	6-8	52.7	34	13	7	7	66.4	188.7	34.2	55.3
10-3	6-9	55.5	35	14	7	7	67.4	278.8	33.5	59.2
10-9	6-10	58.4	36	13	9	7	77.5	139.6	36.8	65.2
11-1	7-0	61.4	37	14	9	7	77.8	172.0	36.1	69.3
11-5	7-1	64 4	38	15	9	7	78.2	222.0	35.3	73.3
11-9	7-2	67.5	39	16	9	7	78.7	309.5	34.4	77.1
12-3	7-3	70.5	40	15	11	7	90.8	165.2	38.4	83.4
12-7	7-5	73.7	41	16	11	7	90.5	200.0	37.5	87.4
12-11	7-6	77.0	42	17	11	7	90 4	251.7	36.5	91.3
13-1	8-2	83.0	43	18	13	6	88.8	143.6	42.0	93.6
13-1	8-4	86.8	44	21	11	6	81.7	300.8	35.8	93.7
13-11	8-5	90.3	45	18	15	6	100 4	132.0	46.0	103.3
14-0	8-7	94 2	46	21	13	6	90.3	215 1	39.4	104.5
13-11	9-5	101.5	47	23	14	5	86.2	159 3	42.8	103 9
14-3	9-7	105.7	48	24	14	5	87 2	176.3	42.0	107.0
14-8	9-8	109.9	49	24	15	5	90.9	166 2	44 0	112.3
14-11	9-10	114.2	50	25	15	5	91 8	183.0	43.2	115.5
15-4	10-0	118.6	51	25	16	5	95.5	173.0	45 3	120.8
15-7	10-2	123.1	52	26	16	5	96.4	189.6	44 4	123.9
16-1	10-4	127 6	53	26	17	5	100.2	179.7	46 6	129.2
16-4	10-6	132.3	54	27	17	5	101.0	196.1	45 7	132.3
16-9	10-8	136 9	55	27	18	5	105.0	186 3	47 9	137.7
17-0	10-10	141 8	56	28	18	5	105.7	202.5	46.9	140.8
17-3	11-0	146.7	57	29	18	5	106.5	221.3	45.9	143.8
17-9	11-2	151.6	58	29	19	5	110.4	208.9	48.2	149.3
18-0	11-4	156.7	59	30	19	5	111 1	227 3	47.2	152.3
18-5	11-6	161.7	60	30	20	5	115.2	215.2	49.6	157 8
18-8	11-8	167.0	61	31	20	5	115.8	233.3	48.5	160 7
19-2	11-9	172.2	62	31	21	5	119 9	221 5	50 9	166.2
19-5	11-11	177 6	63	32	21	5	120 5	239.3	49 8	169.2
19-10	12-1	182.9	64	32	22	5	124 7	227 7	52.3	174 8
20-1	12-3	188.5	65	33	22	5	125.2	245.3	51 1	177 7
20-1	12-6	194 4	66	35	21	5	122.5	310 8	46 2	177.5
20-10	12-7	199 7	67	34	23	5	130 0	251 2	52 5	186.2
21-1	12-9	205.5	68	35	23	5	130 5	270 9	51 2	189 1
21-6	12-11	211.2	69	35	24	5	134 8	257 2	53 9	194 8

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS



Typical Section

Geometric Data—Vehicular Underpass

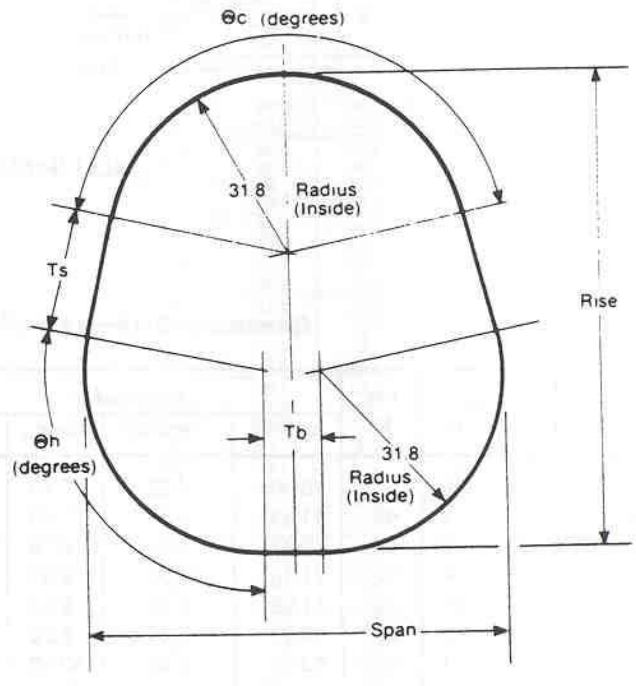
Span Ft	Span In.	Rise Ft	Rise In.	Tot N	Required N Invert	Required N Haunch	Required N Side	Required N Crown	Inside Radius (Inches) Invert	Inside Radius (Inches) Haunch	Inside Radius (Inches) Side	Inside Radius (Inches) Crown
12	1	11	0	47	10.00	4.32	7.69	12.99	135.95	37.95	88.00	67.95
12	10	11	2	49	11.04	4.44	7.50	14.10	148.53	38.53	86.78	74.53
13	0	12	0	51	10.97	4.27	8.79	13.91	160.54	37.54	98.19	72.54
13	8	12	4	53	11.98	4.36	8.67	14.96	167.77	37.77	102.62	76.77
14	0	12	11	55	11.99	4.39	9.62	14.98	182.90	37.90	110.65	76.90
14	6	13	5	57	13.07	4.61	9.26	16.18	174.88	38.88	124.73	78.88
14	8	14	1	59	13.00	4.42	10.58	15.99	192.96	37.96	130.01	78.96
15	5	14	5	61	14.04	4.59	10.33	17.11	201.54	38.54	135.39	83.54
15	6	15	2	63	13.97	4.45	11.61	16.92	211.59	37.59	149.14	81.59
16	2	15	6	65	14.99	4.50	11.52	17.97	216.85	37.85	154.40	85.85
16	6	16	0	67	14.07	4.73	12.10	19.29	272.34	39.34	153.89	89.34
16	8	16	4	68	15.01	4.49	12.49	19.03	246.17	38.17	160.82	89.17
17	3	17	1	70	15.04	5.71	12.20	19.13	214.64	47.64	171.19	90.64
18	5	16	11	72	16.09	5.87	11.95	20.27	249.37	48.37	155.02	100.37
19	0	17	3	74	17.02	5.60	12.36	21.06	262.29	47.29	153.14	105.29
19	7	17	7	76	17.07	5.79	13.06	21.24	296.21	48.21	154.46	108.21
20	5	17	9	78	18.08	5.78	13.05	22.27	317.39	48.39	149.94	115.39

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Geometric Data—Pedestrian/Animal Underpass

Span Ft.-In.	Rise Ft.-In.	Total N	Tb In.	Ts In.	Θc Degrees	Θh Degrees
6-1	5-9	24	9.2	7.2	100.2	129.9
6-3	6-1	25	11.1	11.0	119.3	120.4
6-3	6-6	26	11.6	15.6	136.5	111.7
6-2	7-0	27	10.2	21.1	152.2	103.9
6-3	7-4	28	11.6	25.2	153.3	103.4
6-1	7-10	29	9.8	30.9	161.7	99.2
6-3	8-2	30	11.3	35.0	161.3	99.3

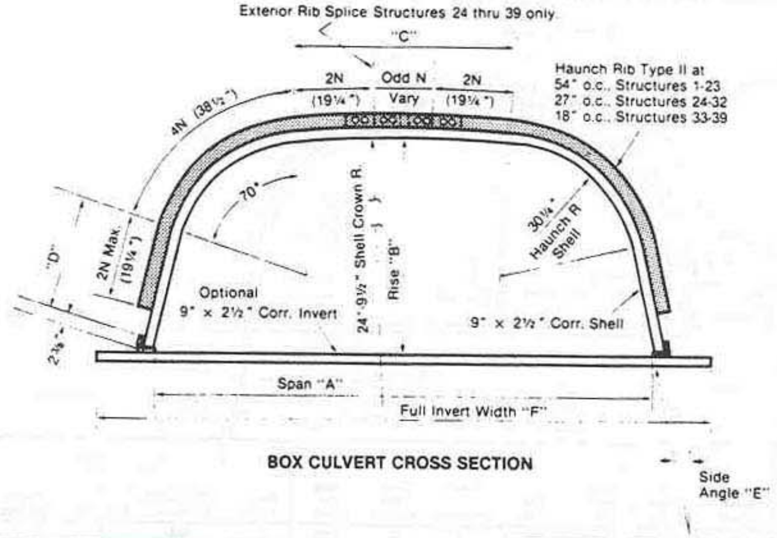


Typical Section

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Box Culvert Geometric Data



BOX CULVERT CROSS SECTION

Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	SHELL: Crown Width "C" (N)	Leg Length "O" (N)	Side Angle "E" Deg. Min.	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts/Ft.	FULL INVERT: Width "F" (N)	Supplemental/Stub Pl Thick.	Supplemental/Stub Pl Width (N)	Weight/Ft.	Bolts/Ft.
1	8- 9	2- 6	18.4	5	.5	15-24	14	1 @ 14	—	6.67	13	—	—	23.06	5.78
2	9- 2	3- 3	25.4	5	1.5	15-24	16	2 @ 8	—	11.56	13	—	—	23.06	5.78
3	9- 7	4- 1	32.6	5	2.5	15-24	18	2 @ 9	—	12.00	14	—	—	24.44	6.00
4	10- 0	4-10	40.2	5	3.5	15-24	20	2 @ 10	—	12.44	14	—	—	24.44	6.00
5	10- 6	5- 7	48.1	5	4.5	15-24	22	2 @ 11	—	12.89	15	—	—	25.82	6.22
6	10-11	6- 4	56.4	5	5.5	15-24	24	2 @ 12	—	13.33	17	—	—	28.58	6.57
7	11- 4	7- 2	65.0	5	6.5	15-24	26	2 @ 13	—	13.78	17	—	—	28.58	6.67
8	10- 2	2- 8	23.0	7	.5	13-33	16	2 @ 8	—	12.89	15	—	—	25.82	6.22
9	10- 7	3- 5	31.1	7	1.5	13-33	18	2 @ 9	—	13.33	15	—	—	25.82	6.22
10	10-11	4- 3	39.5	7	2.5	13-33	20	2 @ 10	—	13.78	17	—	—	28.58	6.57
11	11- 4	5- 0	48.2	7	3.5	13-33	22	2 @ 11	—	14.22	17	—	—	28.58	6.57
12	11- 8	5- 9	57.2	7	4.5	13-33	24	2 @ 12	—	14.67	17	—	—	28.58	6.57
13	12- 1	6- 7	66.4	7	5.5	13-33	26	2 @ 13	—	15.11	17	—	—	28.58	6.57
14	12- 5	7- 4	76.0	7	6.5	13-33	28	2 @ 14	—	15.56	17	—	—	28.58	6.57
15	11- 7	2-10	28.1	9	0.5	11-42	18	2 @ 9	—	14.67	17	—	—	28.58	6.57
16	11-11	3- 7	37.4	9	1.5	11-42	20	2 @ 10	—	15.11	17	—	—	28.58	6.57
17	12- 3	4- 5	46.9	9	2.5	11-42	22	2 @ 11	—	15.56	17	—	—	28.58	6.67
18	12- 7	5- 2	56.6	9	3.5	11-42	24	2 @ 12	—	16.00	19	—	—	32.02	7.11
19	12-11	6- 0	66.6	9	4.5	11-42	26	2 @ 13	—	16.44	19	—	—	32.02	7.11
20	13- 3	6- 9	76.9	9	5.5	11-42	28	2 @ 14	—	16.89	19	—	—	32.02	7.11
21	13- 0	3- 0	33.8	11	0.5	9-52	20	2 @ 10	—	16.44	19	—	—	32.02	7.11
22	13- 4	3-10	44.2	11	1.5	9-52	22	2 @ 11	—	16.89	19	—	—	32.02	7.11
23	13- 7	4- 7	54.8	11	2.5	9-52	24	2 @ 12	—	17.33	19	—	—	32.02	7.11
24	13-10	5- 5	65.6	11	3.5	9-52	26	2 @ 13	—	23.11	19	—	—	32.02	7.11
25	14- 1	6- 2	76.6	11	4.5	9-52	28	2 @ 14	—	23.56	20	—	—	33.34	12.14
26	14- 5	3- 3	40.0	13	0.5	8-1	22	2 @ 11	—	22.67	20	—	—	33.34	12.14
27	14- 8	4- 1	51.5	13	1.5	8-1	24	2 @ 8	8	25.56	21	.100	2	40.23	12.57
28	14-10	4-10	63.2	13	2.5	8-1	26	2 @ 9	8	26.44	21	.100	2	40.23	12.57
29	15- 1	5- 8	75.1	13	3.5	8-1	28	2 @ 10	8	26.89	21	.100	2	40.23	12.57
30	15- 4	6- 5	87.2	13	4.5	8-1	30	2 @ 11	8	27.33	21	.100	2	40.23	12.57
31	15- 6	7- 3	99.4	13	5.5	8-1	32	2 @ 12	8	27.78	22	.100	2	41.61	12.49
32	15- 9	8- 0	111.8	13	6.5	8-1	34	2 @ 13	8	28.22	22	.100	2	41.61	12.49
33	15-10	3- 6	46.8	15	0.5	6-10	24	2 @ 8	8	32.22	22	.100	2	41.61	12.39
34	16- 0	4- 3	59.5	15	1.5	6-10	26	2 @ 9	8	33.56	22	.100	2	41.61	12.49
35	16- 2	5- 1	72.3	15	2.5	6-10	28	2 @ 10	8	34.89	23	.100	2	42.99	13.11
36	16- 4	5-11	85.2	15	3.5	6-10	30	2 @ 11	8	35.33	23	.100	3	45.75	13.11
37	16- 6	6- 8	98.3	15	4.5	6-10	32	2 @ 12	8	35.78	23	.100	3	45.75	13.11
38	16- 8	7- 6	111.5	15	5.5	6-10	34	2 @ 13	8	36.22	23	.100	3	45.75	13.11
39	16-10	8- 3	124.8	15	6.5	6-10	36	2 @ 14	8	36.67	24	.100	3	47.13	13.33

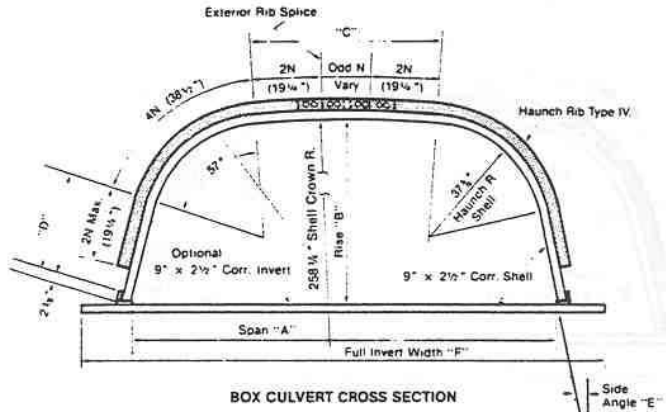
NOTES:

1) "N" equals 9.62".
2) All crowns of shells have Type IV ribs outside at 18" on centers.
3) Weights per foot listed do not include bolt weight.
4) Weight per foot of full invert includes 3½ × 3 × ¼ connecting angle and scalloped closure plate for each side. Inverts for 20N and greater are two-piece.
5) Weight per foot of footing pad includes a 3½ × 3 × ¼-in. connecting angle for each side. Optional wale beam not included.
6) Full invert plates are .100 thick. When reactions to invert require additional thickness supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angle.
7) Width of footing pad is for each side.
8) For structures using short footing pads with leg length "D" equal to 3.5 N or more, either wale beam stiffeners should be used to avoid

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Box Culvert Geometric Data



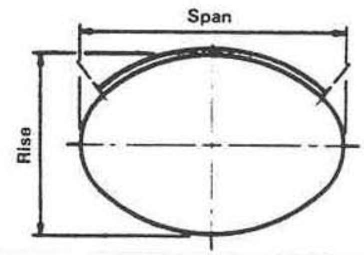
				SHELL							FULL INVERT				
Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	Crown Width "C" (N)	Leg Length "D" (N)	Side Angle "E" Deg. Min.	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts Per Foot	Width "F" (N)	Supplemental Stub Plates Thickness	Supplemental Stub Plates Width (N)	Weight Per Foot	Bolts Per Foot
40	17- 9	3-10	54.4	17	.5	14-54	26	8	10	33.56	25	.100	3	48.51	13.56
41	18- 2	4- 7	68.3	17	1.5	14-54	28	9	10	34.89	25	.100	3	48.51	13.56
42	18- 7	5- 4	82.5	17	2.5	14-54	30	10	10	36.22	26	.100	3	49.88	13.78
43	19- 0	6- 1	97.1	17	3.5	14-54	32	11	10	36.67	27	.100	3	51.26	14.00
44	19- 5	6-11	111.9	17	4.5	14-54	34	12	10	37.11	27	.100	3	51.26	14.00
45	19-10	7- 8	127.1	17	5.5	14-54	36	13	10	37.56	28	.100	3	52.64	14.22
46	20- 3	8- 5	142.6	17	6.5	14-54	38	14	10	38.00	28	.100	3	52.64	14.22
47	19- 1	4- 2	63.3	19	.5	12-47	28	8	12	34.89	27	.100	3	51.26	14.00
48	19- 5	4-11	78.3	19	1.5	12-47	30	9	12	36.22	27	.100	3	51.26	14.00
49	19- 9	5- 8	93.6	19	2.5	12-47	32	10	12	37.56	27	.100	3	51.26	14.00
50	20- 1	6- 6	109.2	19	3.5	12-47	34	11	12	38.00	28	.100	3	52.64	14.22
51	20- 6	7- 3	125.0	19	4.5	12-47	36	12	12	54.44	29	.125	3	56.09	14.44
52	20-10	8- 1	141.2	19	5.5	12-47	38	13	12	54.89	29	.100	3	54.02	14.44
53	21- 2	8-10	157.6	19	6.5	12-47	40	14	12	55.33	30	.150	3	59.54	14.67
54	20- 4	4- 6	73.1	21	.5	10-40	30	8	14	49.56	29	.150	3	58.16	14.44
55	20- 7	5- 3	89.2	21	1.5	10-40	32	9	14	52.22	29	.125	3	56.09	14.44
56	20-11	6- 1	105.5	21	2.5	10-40	34	10	14	54.89	29	.100	3	54.02	14.44
57	21- 3	6-10	122.1	21	3.5	10-40	36	11	14	55.33	30	.150	3	59.54	14.67
58	21- 6	7- 8	139.0	21	4.5	10-40	38	12	14	55.78	30	.125	3	57.47	14.67
59	21-10	8- 5	156.0	21	5.5	10-40	40	13	14	56.22	31	.175	3	62.99	14.89
60	22- 1	9- 3	173.3	21	6.5	10-40	42	14	14	56.67	31	.150	3	60.92	14.89
61	21- 7	4-11	83.8	23	.5	8-32	32	9	14	50.89	30	.125	3	57.47	14.67
62	21-10	5- 8	101.0	23	1.5	8-32	34	10	14	53.56	31	.175	3	62.99	14.89
63	22- 1	6- 6	118.4	23	2.5	8-32	36	11	14	56.22	31	.150	3	60.92	14.89
64	22- 3	7- 3	135.9	23	3.5	8-32	38	12	14	56.67	31	.150	4	65.05	14.89
65	22- 6	8- 1	153.7	23	4.5	8-32	40	13	14	57.11	32	.200	4	71.95	15.11
66	22- 9	8-10	171.6	23	5.5	8-32	42	14	14	57.56	32	.175	4	69.19	15.11
67	23- 0	9- 8	189.8	23	6.5	8-32	44	15	14	58.00	32	.150	4	66.43	15.11
68	22- 9	5- 4	95.5	25	.5	6-25	34	10	14	52.22	32	.175	4	69.19	15.11
69	23- 0	6- 1	113.7	25	1.5	6-25	36	11	14	54.89	32	.150	4	66.43	15.11
70	23- 2	6-11	132.1	25	2.5	6-25	38	12	14	57.56	33	.225	4	76.09	15.33
71	23- 4	7- 8	150.6	25	3.5	6-25	40	13	14	58.00	33	.200	4	73.33	15.33
72	23- 6	8- 6	169.3	25	4.5	6-25	42	14	14	58.44	33	.200	4	73.33	15.33
73	23- 8	9- 3	188.1	25	5.5	6-25	44	15	14	58.89	33	.175	4	70.57	15.33
74	23-10	10- 1	207.0	25	6.5	6-25	46	16	14	59.33	34	.250	4	80.22	15.56
75	24- 0	5- 9	108.2	27	.5	4-18	36	10	16	53.56	34	.225	4	77.46	15.56
76	24- 1	6- 6	127.5	27	1.5	4-18	38	11	16	56.22	34	.225	4	77.46	15.56
77	24- 3	7- 4	146.8	27	2.5	4-18	40	12	16	58.89	34	.200	4	74.71	15.56
78	24- 4	8- 2	166.2	27	3.5	4-18	42	13	16	59.33	34	.200	4	74.71	15.56
79	24- 5	8-11	185.7	27	4.5	4-18	44	14	16	59.78	34	.200	4	74.71	15.56
80	24- 7	9- 9	205.3	27	5.5	4-18	46	15	16	60.22	35	.300	4	87.12	15.78
81	24- 8	10- 6	225.0	27	6.5	4-18	48	16	16	60.67	35	.250	4	81.60	15.78
82	25- 2	6- 2	122.0	29	.5	2-11	38	11	16	54.89	35	.200	4	76.09	15.78
83	25- 2	7- 0	142.2	29	1.5	2-11	40	12	16	57.56	35	.200	4	76.09	15.78
84	25- 3	7- 9	162.4	29	2.5	2-11	42	13	16	60.22	36	.300	4	88.50	16.00
85	25- 4	8- 7	182.6	29	3.5	2-11	44	14	16	60.67	36	.300	4	88.50	16.00
86	25- 4	9- 5	202.9	29	4.5	2-11	46	15	16	61.11	36	.300	4	88.50	16.00
87	25- 5	10- 2	223.3	29	5.5	2-11	48	16	16	61.56	36	.300	4	88.50	16.00

NOTES:

1) "N" = 9.62"
2) All shells have Type IV ribs outside only. Both haunch and crown ribs are 18" on centers for structures 40 through 50 and 9" on centers for structures 51 through 87.
3) Weights per foot listed do not include bolt weight.
4) Weight per foot of full invert includes 3½ x 3 x ¼ connecting angle and scalloped closure plate for each side. Inverts for 20 N width and greater are two piece.
5) Full invert plates are 100" thick. When reactions to invert require additional thickness, supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angles. When thickness listed is greater than a .250" supplemental plates will be two pieces equalling the composite thickness required.
6) Weight per foot of footing pads includes 3½ x 3 x ¼ connecting angle for each side. Optional wale beam weight is not included.
7) Width of footing pads is for each side. When thickness listed is greater than .250" the footing pads will be two pieces equalling the composite thickness required.

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS



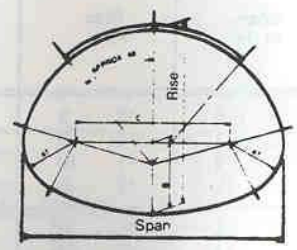
Span Ft.-in	Rise Ft-in.	Area ft²	Required N: Crown or Invert	Required N: Haunch	Required N: Total	Inside Radius: Crown & Invert in.	Inside Radius: Haunch in.
19 4	12 9	191	22	10	64	150.3	53.9
20 1	13 0	202	23	10	66	157.2	53.9
20 2	11 10	183	24	8	64	164.1	42.8
20 10	12 2	193	25	8	66	171.0	42.8
21 0	15 1	248	23	13	72	157.2	70.4
21 11	13 1	220	26	9	70	177.9	48.4
22 6	15 8	274	25	13	76	171.0	70.4
23 0	14 1	249	27	10	74	184.8	53.9
23 3	15 11	288	26	13	78	177.9	70.4
24 4	16 11	320	27	14	82	184.8	75.9
24 6	14 7	274	29	10	78	198.6	53.9
25 3	14 11	287	30	10	80	205.4	53.9
25 6	16 9	330	29	13	84	198.6	70.4
26 1	18 2	369	29	15	88	198.6	81.4
26 3	15 10	320	31	11	84	212.3	59.4
27 0	16 2	334	32	11	86	219.2	59.4
27 2	19 1	405	30	16	92	205.4	86.9
27 11	19 5	421	31	16	94	212.3	86.9
28 1	17 1	369	33	12	90	226.1	64.9
28 10	17 4	384	34	12	92	233.0	64.9
29 5	19 11	455	33	16	98	226.1	86.9
30 2	20 2	472	34	16	100	233.0	86.9
30 4	17 11	415	36	12	96	246.8	64.9
31 2	21 2	513	35	17	104	239.9	92.5
31 4	18 11	454	37	13	100	253.7	70.4
32 1	19 2	471	38	13	102	260.6	70.4
32 3	22 2	555	36	18	108	246.8	98.0
33 0	22 5	574	37	18	110	253.7	98.0
33 2	20 1	513	39	14	106	267.5	75.9
34 1	23 4	619	38	19	114	260.6	103.5
34 8	20 8	548	41	14	110	281.2	75.9
35 0	21 4	574	41	15	112	281.2	81.4
35 2	24 4	666	39	20	118	267.5	109.0
35 10	25 9	719	39	22	122	267.5	120.0
36 1	22 4	620	42	16	116	288.1	86.9
36 11	25 7	736	41	21	124	281.2	114.5
37 2	22 2	632	44	15	118	301.9	81.4
38 0	26 7	786	42	22	128	288.1	120.0
38 8	28 0	844	42	24	132	288.1	131.0
40 1	29 8	928	43	26	138	295.0	142.1

SOURCE: ALUMINUM ASSOCIATION

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Geometric Data—Pipe Arch

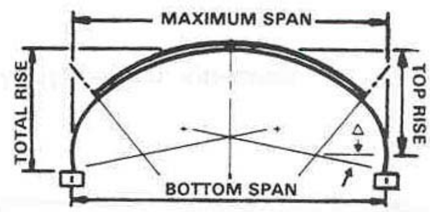


Span Ft-in	Rise Ft-in.	Area ft²	Required N				Inside Radius		B	C
			Total	Crown	Invert	Haunch	Crown in.	Invert in.		
20 1	13 11	216	68	34	20	7	122.7	224.2	62.9	146.7
20 7	14 3	229	70	36	20	7	124.9	256.4	61.4	152.8
21 5	14 7	241	72	36	22	7	131.7	237.3	65.4	163.4
21 11	14 11	254	74	38	22	7	133.7	268.8	63.8	169.4
22 8	15 3	267	76	39	23	7	138.2	274.9	65.0	177.8
23 4	15 7	281	78	40	24	7	142.7	281.0	66.3	186.1
24 3	15 10	295	80	40	26	7	150.0	262.8	70.8	196.8
24 9	16 3	309	82	42	26	7	151.7	293.0	68.9	202.9
25 5	16 7	324	84	43	27	7	156.2	299.0	70.2	211.3
26 4	16 10	339	86	43	29	7	163.9	281.3	75.0	222.1
27 0	17 2	354	88	44	30	7	168.6	287.4	76.4	230.5
27 9	17 6	369	90	45	31	7	173.3	293.5	77.9	238.9
28 5	17 10	385	92	46	32	7	178.0	299.6	79.3	247.3
29 4	18 2	401	94	46	34	7	186.6	286.7	84.6	257.9
29 10	18 6	418	96	48	34	7	187.5	311.6	82.3	264.2
30 4	18 10	435	98	50	34	7	188.6	340.1	80.0	270.2

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Geometric Data—Low Profile Arch



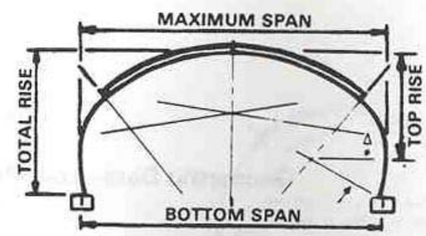
Max. Span Ft-in.		Total Rise Ft-in		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N			Inside Radius		Δ	
									Crown	Side	Total	Crown In.	Side In.	Deg.	Min.
20	1	7	6	120	19	10	6	6	23	6	35	157.2	54.0	12	19
19	5	6	9	105	19	2	5	10	23	5	33	157.2	43.0	15	22
21	6	7	9	133	21	4	6	9	25	6	37	171.0	54.0	12	19
22	3	7	11	140	22	1	6	11	26	6	38	177.9	54.0	12	19
23	0	8	0	147	22	10	7	1	27	6	39	184.8	54.0	12	19
23	9	8	2	154	23	6	7	2	28	6	40	191.7	54.0	12	19
24	6	8	3	161	24	3	7	4	29	6	41	198.6	54.0	12	19
25	3	8	5	168	25	0	7	5	30	6	42	205.4	54.0	12	19
26	0	8	7	175	25	9	7	7	31	6	43	212.3	54.0	12	19
27	3	10	0	217	27	1	9	0	31	8	47	212.3	76.0	8	51
28	1	9	6	212	27	11	8	7	33	7	47	226.1	65.0	10	17
28	9	10	3	234	28	7	9	3	33	8	49	226.1	76.0	8	52
28	10	9	8	220	28	8	8	8	34	7	48	233.0	65.0	10	17
30	4	9	11	237	30	2	9	0	36	7	50	246.8	65.0	10	17
31	0	10	8	261	30	10	9	8	36	8	52	246.8	76.0	8	52
31	7	12	1	309	31	2	10	4	36	10	56	246.8	87.0	14	0
31	1	10	1	246	30	10	9	1	37	7	51	253.7	65.0	10	17
32	4	12	3	319	31	11	10	6	37	10	57	253.7	87.0	14	0
31	9	10	2	255	31	7	9	3	38	7	52	260.6	65.0	10	17
33	1	12	5	330	32	8	10	8	38	10	58	260.6	87.0	14	0
33	2	11	0	289	33	0	10	1	39	8	55	267.5	76.0	8	52
34	6	13	3	367	34	1	11	6	39	11	61	267.5	98.0	12	26
34	8	11	4	308	34	6	10	4	41	8	57	281.2	76.0	8	52
37	11	15	7	478	37	8	13	10	41	14	69	281.2	131.0	9	23
35	5	11	5	318	35	3	10	6	42	8	58	288.1	76.0	8	52
38	8	15	9	491	38	4	14	0	42	14	70	288.1	131.0	9	23

See "Notes" Table 5-20A or 5-20B for rib spacing when required.

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES FOR ALUMINUM CULVERTS

Geometric Data—High Profile Arch



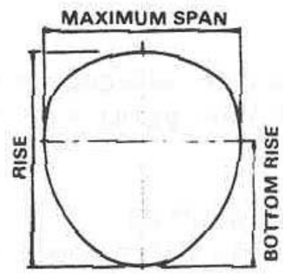
Max Span Ft.-in.		Total Rise Ft.-in.		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N				Inside Radius			Δ	
									Crown	Haunch	Side	Total	Crown in.	Haunch in.	Side in.	Deg.	Min.
20	1	9	1	152	19	6	6	6	23	5	3	39	157.2	54.0	157.2	11	40
20	9	12	1	214	18	10	7	3	23	6	6	47	157.2	65.0	157.2	22	8
21	6	11	8	215	19	10	6	9	25	5	6	47	171.0	54.0	171.0	20	20
22	10	14	6	284	19	10	8	6	25	7	8	55	171.0	76.0	171.0	26	48
22	3	11	9	224	20	7	6	11	26	5	6	48	177.9	54.0	177.9	19	33
22	11	14	0	275	20	1	7	7	26	6	8	54	177.9	65.0	177.9	25	44
23	0	11	11	234	21	5	7	1	27	5	6	49	184.8	54.0	184.8	18	49
24	4	14	10	309	21	7	8	5	27	7	8	57	184.8	76.0	184.8	24	50
23	9	12	1	244	22	2	7	2	28	5	6	50	191.7	54.0	191.7	18	8
24	6	13	8	288	21	11	7	4	29	5	8	55	198.6	54.0	198.6	23	2
25	10	15	1	334	23	3	8	9	29	7	8	59	198.6	76.0	198.6	23	6
25	3	13	1	283	23	3	7	5	30	5	7	54	205.4	54.0	205.4	19	35
26	6	15	3	347	24	0	8	10	30	7	8	60	205.4	76.0	205.4	22	19
26	0	13	3	294	24	1	7	7	31	5	7	55	212.3	54.0	212.3	18	57
27	3	15	5	360	24	10	9	0	31	7	8	61	212.3	76.0	212.3	21	36
27	5	13	6	317	25	8	7	10	33	5	7	57	226.1	54.0	226.1	17	48
29	5	16	5	412	27	1	10	0	33	8	8	65	226.1	87.0	226.1	20	18
28	2	14	5	348	25	11	8	0	34	5	8	60	233.0	54.0	233.0	19	37
30	2	18	0	466	26	8	10	2	34	8	10	70	233.0	88.0	233.0	23	51
30	4	15	5	399	28	2	9	0	36	6	8	64	246.8	65.0	246.8	18	34
31	7	18	4	497	28	5	10	4	36	8	10	72	246.8	87.0	246.8	23	3
31	1	15	7	412	29	0	9	1	37	6	8	65	253.7	65.0	253.7	18	3
31	8	17	9	483	28	7	9	10	37	7	10	71	253.7	76.0	253.7	22	25
32	4	19	11	554	27	11	10	6	37	8	12	77	253.7	87.0	253.7	26	45
31	9	17	2	469	28	9	9	3	38	6	10	70	260.6	65.0	260.6	21	47
33	1	20	1	571	28	9	10	8	38	8	12	78	260.6	87.0	260.6	26	3
32	6	17	4	484	29	6	9	4	39	6	10	71	267.5	65.0	267.5	21	14
33	10	20	3	588	29	7	10	9	39	8	12	79	267.5	87.0	267.5	25	23
34	0	17	8	514	31	2	9	8	41	6	10	73	281.2	65.0	281.2	20	11
34	8	19	10	591	30	7	10	4	41	7	12	79	281.2	76.0	281.2	24	7
35	4	21	3	645	30	7	11	0	41	8	13	83	281.2	87.0	281.2	26	6
37	3	23	4	747	32	7	13	2	41	11	13	89	281.2	120.0	281.2	26	8
34	9	17	9	529	31	11	9	9	42	6	10	74	288.1	65.0	288.1	19	42
35	5	20	0	608	31	5	10	6	42	7	12	80	288.1	76.0	288.1	23	33
36	1	21	5	663	31	5	11	2	42	8	13	84	288.1	87.0	288.1	25	28
38	0	23	6	767	33	5	13	3	42	11	13	90	288.1	120.0	288.1	25	31

See "Notes" Table 5-20A or 5-20B for rib spacing when required.

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pear Shape



Max. Span Ft.-in.	Rise Ft.-in.	Rise Bottom Ft-in.	Area ft^2	Required N					Inside Radius			
				Top	Corner	Side	Bottom	Total	Bottom in.	Side in.	Corner in.	Top in.
23 7	25 6	14 10	477	25	5	24	15	98	108.31	198.07	74.07	175.07
24 0	25 10	15 1	497	22	7	22	20	100	119.07	208.07	84.07	194.07
25 4	25 11	15 10	518	27	7	20	20	102	124.23	218.24	84.24	191.24
24 10	27 7	16 9	545	27	5	25	18	105	110.90	236.21	69.21	191.21
28 10	27 3	19 8	590	32	7	27	8	110	79.61	257.96	68.96	252.96
26 8	28 3	18 0	594	28	5	30	12	110	95.45	241.24	57.24	251.24
28 0	27 10	16 9	624	27	8	22	25	112	146.38	227.72	86.72	244.72
28 7	30 7	19 7	690	32	7	24	24	118	133.13	288.45	84.45	218.45
30 0	29 7	20 0	699	32	8	23	25	119	142.41	288.26	79.26	262.26
30 0	31 2	19 11	739	34	7	24	26	122	144.43	·288.58	84.58	231.58

Figure 12.4.45 Standard Sizes for Aluminum Culvert (Source: Aluminum Association), continued